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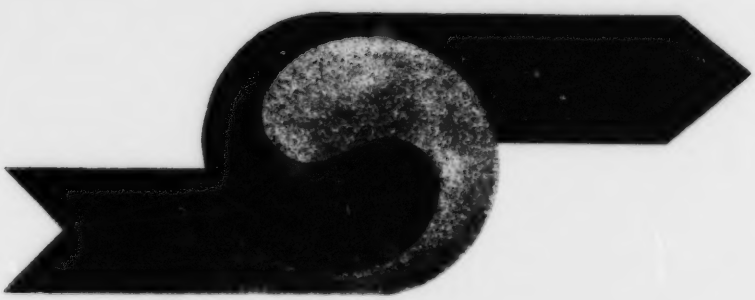
Recovery of Heat from Salt Water in the Fish Processing Industry

Interprovincial Engineering Ltd.

March 1983



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REPORT

to

NATIONAL RESEARCH COUNCIL

on

RECOVERY OF HEAT FROM SALT WATER IN THE FISH PROCESSING INDUSTRY

MARCH 1, 1983

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EXECUTIVE SUMMARY

In August,1982, Interprovincial Engineering Limited received authorization to proceed with an investigation of a heat pump design to extract thermal energy from saltwater being used in Clearwater Lobsters Limited's fish plant in Clark's Harbour, Nova Scotia.

The project involved preliminary design, selection of major components, preparation of an economic viability analysis and identification of specific energy savings for the heat pump and potential economic benefits on nation-wide basis.

Seawater as a heat source for industrial heat pumps differs from most other applications in that:

- The mean annual temperature of seawater along Canada's coastlines is relatively low;
- There are significant fluctuations in the heat source temperature throughout the year;
- Seawater is very corrosive; and
- Excessive fouling due to biological marine growth is possible.

While seawater is a new application for heat pumps, there are literally hundreds of thousands of heat exchangers used on ships and submarines throughout the world. The ocean source heat pump is a result of a marriage of this experience with recent technological advances in the design

of groundwater heat pumps.

Definition of the design parameters for the heat pump installation in consultation with personnel from Clearwater Lobsters Limited highlighted the importance of establishing control over the seawater temperature within the lobster holding tanks. In particular, the potential decrease in mortality and improvement in quality that would accrue from elimination of excessively warm temperatures in the summer and early fall was emphasized. The decrease in mortality is estimated to be worth $175,000.00 per year.

It was established that the heat pump must be located on the seawater supply line to the plant if adequate control of the temperature within the holding tanks is to be maintained. Subsequent evaluation of equipment configuration alternatives and expected performance resulted in the identification of three technically viable options:

- Option 1 provides the maximum useable heat during the summer; however, economical operation is limited to a period from April until December. Efficient utilization of the heat is difficult since the quantity available fluctuates dramatically. The total cost to design, install and commission the system is estimated to be $835,000.00.

- Option 2 is the optimum system for providing a relatively constant supply of heat year round while at the same time strictly controlling the seawater temperature within the plant. The total cost to design, install and commission the system is estimated to be $489,000.00.

. Option 3 identifies the system selected for Clearwater Lobsters Limited. Heat output is identical to option 2; however, a relatively minor fluctuation in seawater temperature is permitted. All the economic benefits are retained and there is a significant reduction in the complexity of the operational control required. The total cost to design, install and commission the system is estimated to be $452,900.00.

Selecting the third option for Clearwater Lobsters Limited, provides maximum benefit for the least capital cost. Operation of the system is also straight forward which simplifies the training program for the operators and reduces the potential that the equipment will be operated below it's optimum capabilities.

The annual cost to operate the heat pump is estimated to be $71,800.00. A value for the energy savings available to Clearwater is calculated by establishing the cost to supply an equal amount of heat using the cheapest conventional form of energy available. In Nova Scotia the cost to supply the fuel for an oil fired furnace is $206,610.00. The potential saving therefore is $134,810.00 plus maintenance and electrical costs for the oil fired furnace.

Clearwater Lobsters limited will be unable to fully utilize the heat available immediately upon start-up of the system since the current heat demand within their facility is minimal. They will however require the entire output of the heat pump in the very near future when they incorporate into their plant a revolutionary new lobster storage concept

requiring substantial quantities of seawater to be heated to 15.5°C. The heat pump is the cornerstone for the new system since it is the only economically competitive system capable of supplying both heated and cooled seawater simultaneously. Complete conversion of the plant prior to verification of the reliability of the heat pump is not practical since total system shutdown for adjustments during commissioning and trials would possibly jeopardize $1,000,000.00 worth of inventory. A controlled step by step implementation schedule is necessary to minimize financial risks during the transition stage.

Prior to full implementation of the new heated holding system, it is estimated that the value to Clearwater Lobsters Limited of the energy used plus cooling benefits will be $200,000.00. The payback period for this application will therefore be 3.53 years. Once the reliability of the heat pump is demonstrated and the total heat available is then utilized, the annual value of the system to Clearwater Lobsters Limited will increase to $381,610.00 and the payback period will diminish to 1.52 years.

The majority of the approximately 520 fishplants throughout the country are located in Eastern Canada. The value of all the energy that is available in the seawater they currently use would replace $213,510,655.00 of imported oil. Unlike the lobster industry most of fishplants do not have a requirement for cooled seawater; however, they already use

significant quantities of heat in many of their operations. Reliable ocean source heat pumps could be integrated directly into existing or upgraded facilities to reap immediate benefit without a requirement to significantly alter existing distribution equipment or operating parameters.

Installation of this demonstration system at Clearwater Lobsters Limited will have many long term benefits:

- Canada will reduce it's dependence on imported foreign oil;
- Operators of fishplants will reduce overhead costs which in turn will increase their ability to compete in world markets;
- There will be greater demand for the catches of local fishermen;
- Biological research into new methods of improving the quality of processed fish will be stimulated;
- Employment will be increased in fishplants since it will be profitable to stay open longer;
- Canada will be the world leader in the development of a new technology which in turn will provide many opportunities for consulting engineers to obtain Canadian and foreign contracts;
- Experience with the prototype equipment will ensure Canadian manufacturers have the opportunity to establish themselves as the principal suppliers of ocean source heat pumps for world markets;
- The heat pumps will be used in other existing domestic, commercial and industrial installations located near saltwater such as:
  - shipyards

- pulp and paper mills
- hotels
- condominium complexes
- office buildings
- recreational facilities
- offshore supply bases
- shopping centers

. Development of systems to preheat boiler feedwater, supply hotwater for de-icing and provide domestic heating and hotwater for ships, submarines and oil rigs will be stimulated;

. Development of systems for use in the arctic will reduce the volume of very expensive hydrocarbons that is currently required to supply fundamental heating requirements. The use of the heat pump will simultaneously help to reduce atmospheric pollution.

The potential applications for ocean source heat pumps are unlimited and the economic benefits are sufficient to encourage private enterprise to actively persue technological advances that will give them an advantage in the world marketplace. A pilot plant demonstrating the technology is the catalyst required to help the country reduce it's dependence on conventional hydro-carbon fuels and initiate a new Canadian industry. Employment opportunities will be widespread and include fishermen, fish plant personnel, equipment manufacturers, skilled tradesmen, salesmen, research personnel and consulting engineers.

RÉSUMÉ ADMINISTRATIF

En août 1982, l'Interprovincial Engineering Limited recevait l'autorisation d'entreprendre une étude sur la conception d'une pompe de chaleur destinée à extraire l'énergie thermique de l'eau de mer; cette pompe est présentement utilisée à l'usine de préparation de la Clearwater Lobsters Limited de Clark's Harbour (Nouvelle-Écosse).

Le projet comprenait la conception préliminaire, le choix des principales composantes, la préparation d'une analyse de rentabilité, la détermination des économies d'énergie réalisées grâce à la pompe et les avantages économiques éventuels pour l'ensemble du pays.

L'utilisation de l'eau de mer comme source de chaleur dans une pompe de chaleur industrielle diffère de la plupart des autres applications car:

- La température annuelle moyenne de l'eau de mer le long des côtes canadiennes est assez basse;
- La température de la source de chaleur fluctue beaucoup tout au long de l'année;
- L'eau de mer est très corrosive; et
- Il y a possibilité de fixation d'une trop grande quantité de salissures due à la prolifération d'espèces biologiques marines.

L'utilisation de l'eau de mer dans les pompes de chaleur est une nouvelle application; toutefois, il y a littéralement des

centaines de milliers d'échangeurs de chaleur à bord des navires et des sous-marins qui sillonnent le monde. L'utilisation des eaux océaniques comme source de chaleur pour ces pompes vient du couplage de l'expérience et des progrès technlogiques récents réalisés lors de la conception des pompes de chaleur fonctionnant à l'eau souterraine.

La définition des paramètres relatifs à l'installation de la pompe de chaleur, qui s'est faite en collaboration avec le personnel de la Clearwater Lobsters Limited, a révélé l'importance de réussir à régler la température de l'eau de mer à l'intérieur des bassins d'élevage de homards. On a surtout insisté sur la diminution possible de la mortalité et l'amélioration de la qualité qui pourraient résulter de l'élimination de températures trop chaudes en été et en début d'automne. On estime que la diminution de la mortalité peut rapporter 175 000,00 $ par année.

On a déterminé que la pompe de chaleur doit être située dans la conduite d'alimentation de l'usine en eau de mer si on veut assurer une régulation efficace de la température dans les bassins d'élevage. Par la suite, l'évaluation des configurations possibles de l'équipement et de l'efficacité prévue a permis de déterminer trois techniques applicables:

. La première technique assure la quantité maximale de chaleur utilisable pendant l'été;

toutefois, la période rentable d'utilisation se limite à une période allant d'avril à décembre. Il est difficile d'utiliser efficacement la chaleur car la quantité fournie varie de façon remarquable. On évalue l'ensemble de la conception, de l'installation et de la mise en service du système à 835 000,00 $.

. La deuxiéme technique est la meilleure pour ce qui est d'assurer une source assez constante de chaleur tout au long de l'année, en même temps qu'une régulation stricte de la température de l'eau de mer à l'intérieur de l'usine. On évalue l'ensemble de la conception, de l'installation et de la mise en service du système à 489 000,00 $.

. La troisime technique est celle choisie à la Clearwater Lobsters Limited. La chaleur récupérée est la même qu'avec la technique 2; cependant, une fluctuation assez faible de la température de l'eau de mer est permise. Tous les avantages économiques sont conservés et le fonctionnement demande un réglage beaucoup moins complexe. On évalue l'ensemble de la conception, de l'installation et de la mise en service du système à 452 000,00 $.

Le choix de la troisième technique par la Clearwater Lobsters Limited assure un maximum d'avantages pour un investissement minimum. De plus, le fonctionnement du système est très simple, ce qui rend plus facile la formation des opérateurs et réduit la possibilité de sous-utilisation de l'équipement.

Les frais annuels de fonctionnement de la pompe de chaleur sont évalués à 71 800,00 $. On évalue les économies d'énergie réalisées par la Clearwater en déterminant les coûts encourus pour fournir une quantité égale de chaleur en se servant de la

source d'énergie classique la moins coûteuse. En Nouvelle-Écosse, le coût d'alimentation en carburant d'un four à l'huile lourde est de 206 610,00 $. Les économies possibles sont donc de 134 810,00 $, auxquelles il faut ajouter les frais d'entretien et d'electricité nécessités par le four à l'huile lourde.

La Clearwater Lobsters Limited ne pourra pas utiliser toute la chaleur récupérée immédiatement au moment de la mise en place du système car les besoins actuels de chaleur à l'intérieur de leurs installations sont minimums. Elle aura cependant besoin de toute la chaleur récupérée par la pompe dans un futur très rapproché lorsque sera introduit dans l'usine un système révolutionnaire de stockage du homard nécessitant le chauffage de quantités importantes d'eau de mer à une température de 15,5°C. Le nouveau système repose sur la pompe de chaleur qui est le seul appareil compétitif capable aussi bien de chauffer que de refroidir l'eau de mer. Il ne serait pas pratique de transformer complètement l'usine avant d'avoir vérifié la fiabilité de la pompe de chaleur car la fermeture totale du système pour des réglages pendant les essais et la mise en service mettrait en danger un inventaire d'une valeur de 1 000 000,00 $. Il est donc nécessaire d'avoir un calendrier de mise en place par étapes de façon à minimiser les risques financiers pendant la transition.

On estime que, d'ici la fin de la mise en place des nouveaux bassins chauffés, l'énergie économisée par la Clearwater Lobsters Limited ainsi que les avantages apportés par le refroidissement auront une valeur de 200 000,00 $. La période d'amortissement pour ce genre d'utilisation serait donc de 3,53 années. Lorsqu'il aura été démontré que la pompe de chaleur est fiable et que la chaleur récupérée sera toute utilisée, le système rapportera annuellement à la Clearwater Lobster Limited 381 610,00 $ et la période d'amortissement tombera à 1,52 année.

Il existe au pays quelque 520 usines à poissons dont la majorité sont situés dans l'est du Canada. La valeur de toute l'énergie qui se trouve dans l'eau de mer utilisée actuellement remplacerait 213 510 655,00 $ de pétrole importé. A l'encontre de l'industrie du homard, la plupart des usines à poissons ne se servent pas d'eau de mer refroidie; par contre, beaucoup de leurs opérations demandent déjà des quantités importantes de chaleur. Des pompes de chaleur fiables absorbant l'énergie de l'océan pourraient être intégrées directement, ou après amélioration, dans les usines existantes pour recueillir immédiatement des bénéfices sans avoir besoin de modifier beaucoup l'équipement de distribution actuel ou les paramètres de fonctionnment.

. Le Canada sera moins tributaire des pays étrangers pour le pétrol;

. Les frais généraux des usines à poissons seront réduits; celles-ci seront donc plus compétitives sur les marchés mondiaux;

. La demande de prises augmentera pour les pêcheurs locaux;

. Des recherches biologiques sur les nouvelles méthodes seront suscitées qui permettront d'améliorer la qualité du poisson traité;

. Les emplois augmenteront aux usines à poissons car il sera avantageux de produire plus longtemps;

. Le Canada sera à la tête du monde en matière de développement d'une nouvelle technologie; les ingénieurs-conseils auront donc beaucoup d'occasions de passer des contrats avec des firmes canadiennes et étrangères;

. L'expérience acquise avec le prototype assurera aux fabricants canadiens l'occasion de s'établir sur le marché mondial les principaux fournisseurs de pompe récupérant la chaleur de l'océan;

. Les pompes de chaleur seront utilisées dans d'autres installations domestiques, commerciales et industrielles situées près de la mer:

- chantiers navals
- usine de pâtes et papiers
- hôtels
- copropriétés
- édifices à bureaux
- centres récréatifs
- bases d'alimentation en mer
- centres commerciaux

. On sera incité à mettre au point des systèmes permettant le préchauffage de l'eau d'alimentation des chaudières, l'alimentation en eau chaude destinée à faire fondre la glace, le chauffage des maisons et l'alimentation en eau chaude des navires, des sous-marins et des plates-formes de forage;

. Le volume d'hydrocarbures très coûteux nécessaire actuellement dans l'arctique pour le chauffage de base diminuera grâce au développement de systèmes pouvant y être utilisés. L'utilisation de la pompe de chaleur permettra en même temps de réduire la pollution atmosphérique.

Les applications potentielles des pompes récupérant la chaleur de l'océan sont illimitées et les avantages économiques qui en découlent suffisent à encourager l'entreprise privée à chercher activement à faire des progrès technologiques qui lui assureraient un avantage sur le marché mondial. La démonstration en usine pilote que la technologie est applicable est le catalyseur nécessaire pour aider notre pays à dépendre moins des carburants classiques à base d'hydrocarbures, et donner naissance à une nouvelle industrie canadienne. Un grand nombre d'emplois seront suscités, entre autre: pêcheurs, personnel d'usines à poissons, fabricants d'équipement, employés spécialisés, vendeurs, personnel de recherches et ingénieurs-conseils.

1.0 AUTHORIZATION AND TERMS OF REFERENCE

Authorization for this study is given in a contract between the National Research Council of Canada (NRC) and Interprovincial Engineering Limited (IPE) dated August 20, 1982 ; Department of Supply and Services (DSS) file number 01SX.31155-2-2680.

Terms of Reference for this feasability study are in accordance with the proposal submitted by IPE dated April 28, 1982 and the statement of work attached to contract serial number 0SX82-00079 as annex "A". A copy of this statement of work is attached to this report as Appendix "A".

2.0 INTRODUCTION

2.1 Background

On April 1, 1982, NRC solicited proposals for novel applications of heat pumps for industrial purposes. Emphasis was to be directed to specific plant applications; however, the general objectives were:

- The expansion of the use of heat pumps into areas without previous operating experience;
- The identification of areas where equipment development is required;
- The determination of design parameters which are important in heat pump waste heat recovery systems; and
- The monitoring of installations in a variety of applications to promote extensive waste heat recovery.

The proposal submitted on the recovery of heat from process saltwater showed how a demonstration system at Clearwater Lobsters Limited would fulfill all of these objectives. In particular it showed the benefits to Canada's fish processing industry. By establishing

operating information on the economics of heat recovery from saltwater, commercialization will spread to other industries currently using or having access to the ocean.

From a review of all literature available on heat pumps and discussions with leading heat pump experts from 18 countries, it is believed that no other research is actively being carried out in this area.

2.2 Study Objective

The primary objective of this particular study is to:

EVALUATE THE TECHNICAL AND ECONOMIC FEASABILITY OF UTILIZING SEAWATER AS A HEAT SOURCE FOR INDUSTRIAL HEAT PUMPS

The emphasis in this project is directed towards establishing a demonstration site where monitoring and evaluation of the performance of a heat pump's capability to extract heat from the ocean economically and reliably is the most critical factor. The ocean differs from other heat sources for industrial applications in that;

- the temperature is very low
- the temperature varies widely over a 12 month cycle

- seawater is corrosive
- fouling is a problem

2.3 Demonstration Site

The overiding criteria for carrying out the feasability study was that the evaluation had to be carried out for a specific application. As with any waste heat recovery project, care must be taken not to disrupt the process to which new equipment is being added. Consequently finding a site to demonstrate the ocean source heat pump was difficult. Because the aim of the project is to prove the fact that heat can be extracted from the ocean, unqualified assurances cannot yet be given to the quantites of heat available or the reliability of the equipment supplying it. In these tough times industry is reluctant to gamble on theoretical calculations.

Clearwater Lobsters Limited is an innovative company that has been devoting a great deal of time and money to modernizing both marketing and storage methods for lobsters destined for international markets. As a result of their efforts, a profitable export industry is continuing to expand. Recognizing that the lobster industry has not incorporated many of the technological advances of the past 50 years, they are in dire need of innovative solutions to catch up. This requires some

element of risk.

Utilization of a heat pump at Clearwater will not only allow the heat pump to be evaluated, it will also demonstrate the benefits a constant supply of cold seawater will have for the fish processing industry. If temperature can be controlled in the summer and fall, the economics of lobster storage may be radically improved. Teething problems with the new system will not adversely affect Clearwater since the benefit from cold water is not currently being supplied from another source. A new system would be required to achieve their aims whether it was a heat pump or demonstration refrigeration unit.

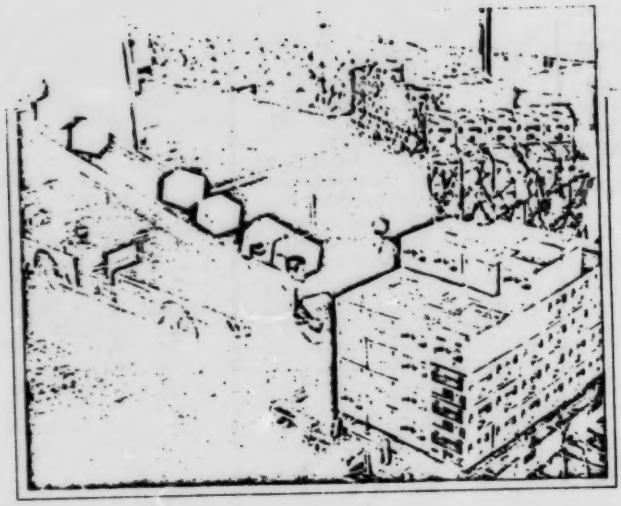
The dual benefits of a heat pump in this application will help to demonstrate the versatility with which heat pumps can be utilized. Heat pumps will not be dismissed as another conservation fad but as an economically valuable alternative to existing equipment options.

3.0 CLEARWATER LOBSTERS LIMITED

Clearwater lobsters limited was incorporated in 1976 as a wholesale and retail distributor of lobster and lobster products. The company operates plants at Halifax and Clark's Harbour, Nova Scotia and buy stations at Point Aconi, Big Bras D'Or and Gabarus, Cape Breton and Piccadilly, Newfoundland. Employment varies from 75 to 140 depending upon the season. Clearwater also operates a wholly owned subsidiary in South Fambridge, England which distributes Canadian lobsters throughout the United Kingdom and Scottish lobsters in Europe.

As of September 30, 1982 the paid up share value in Clearwater Lobsters Limited was $1,533,901.00. The principal shareholders include management personnel (60%), The Federal Business Development Bank (20%) and Industrial Estates (10%). The company has credit facilites through the Continental Bank of Canada.

Clearwater Lobsters Limited is the largest exporter of lobster in Canada. It has been through their efforts that the European market for Canadian lobster has been expanded. The export growth potential for this industry and the impact on Atlantic Canada's economy is highlighted in the magazine article on the next two pages from the February 1983 edition of "Atlantic Business".



High-flying lobster set to conquer new markets

Special product, special problems

By
CHRISTOPHER DUNCAN

What do you do when your chartered air freighter is stranded in Florida and you have 50,000 pounds of live lobster in Halifax packed for a flight that must be in Brussels in the morning?

A call for divine intervention may help. But John Risley, president of Clearwater Lobsters Ltd. of Bedford, N.S. says the only real solution to any transportation problem is to know as much about the business as the carrier himself.

In the case of the stranded cargo plane, caught in the fuel supply shortage of a few years ago, the problem was solved with a lot of telephoning and some vigorous moving and shaking. The delectable crustaceans arrived on time for the pre-Christmas European lobster spending spree.

But from such bitter experience, Mr. Risley says he has learned that with a perishable commodity as valuable as lobsters and with up-front air charter costs of $80,000 or $90,000, nothing should be left to chance.

"You just can't say to an airline, there you are, take over. We monitor our shipments every mile of the way."

Lobsters are the largest single export commodity shipped out of Atlantic Canada. They mean steady, lucrative air freight business for the region's three main air carriers, Air Canada, Eastern Provincial and CP Air.

According to Gordon Dossett, cargo sales manager for Air Canada in Nova Scotia, the principal destination remains Paris, closely followed by the Benvelux countries, Germany and the U.K.

While some lobster moves at most times during the year, the Christmas period provides the big rush. A year ago, more than 600,000 pounds were shipped through Halifax International Airport during December. Providing supplies hold up and currency devaluations in Europe don't depress the market, he expects the holiday season this year will have produced about a 10 to 15 percent increase in volume.

Clearwater is the biggest of half a dozen major shippers. Others in Nova Scotia include the National Sea Products — H.B. Nickerson Group of North Sydney, Seaglobe of Clarke's Harbour, Ryer and Ryer of Indian Harbour, Fish Basket of East Prospect and Goyetche Lobsters of Jeddore.

Among the biggest buyers are Primel SA of France and DeMeulemeester & Cie of Amsterdam. The lobsters are sold either through other individual wholesalers directly or through some of the big wholesale fish markets, such as The Rungis Market in Paris and the New Billingsgate Market in London.

Each year representatives of the principal buyers visit the Maritimes, usually warning of market resistance if prices are not contained. Each year, however, it seems consumers somehow find the necessary cash to buy them, paying anything between $12.50 and $15 a pound, or about three times the local wholesale price in Canada at the time of

shipment.

This results from the addition of freight costs — about 90 cents a pound — plus duty and taxes which collectively double the Canadian wholesale price. On top of this is the retailer markup. While fishermen naturally grumble that they don't see very much of the final price, the primary producer benefits to the tune of about $80-million annually from lobster landings of about 14,000 metric tons in the four Atlantic Provinces and Quebec. They provide employment for about 10,000 fishermen. And if this hasn't satiated your appetite for statistics, the Maritime segment of the industry lands its lobsters in 1.9 million pots, according to the Department of Fisheries and Oceans.

Mr. Risley attributes much of the continued strength of the European retail lobster market to the way the product is presented there. He says the North American retail food industry still has a lot to learn about fish merchandising. Clearwater's contribution to the exercise is a sparkling new, $500,000 seafood store at Bedford. The company has plans to duplicate the concept across the continent. But while it has engaged a European chef to expand its line of prepared specialty food items, it has had to delay additional store openings in Canada and the United States until capital and economic conditions improve.

While lobsters are already a big export item, the potential exists for considerable further expansion. With good lines of communication and distribution and a generally stable consumer market not as easily buffeted by the winds of economic change as that in North America, Mr. Risley says Europe offers the possibility of continued steady demand growth.

> Europe offers the possibility of continued steady demand growth . . . the Orient is the next big market.

Belgium, Germany, Switzerland and the Scandinavian countries are all developing markets and even France, where the Franc has been effectively devalued against the dollar by almost 50 percent over the past two years, continues to buy well.

He said CP Air's introduction of its Halifax-Amsterdam flight has increased the direct shipping possibilities out of the Maritimes. Air freight revenue generated by lobsters is not inconsiderable. Clearwater alone spends between $2.5-million and $3-million annually. The trade helped make Halifax one of the fastest growing freight markets in the country, justifying construction of Air Canada's new $5-million cargo handling terminal at the International Airport, due to open later this year.

Buyers like Primel and DeMeulemeester warn that price resistance is about to set in but of greater concern to the shippers is the added cost they face in getting the product to market. Mr. Risley says air freight costs have been going up at a faster rate than inflation but he says this has been somewhat offset by the fact that empty passenger seats on scheduled airline routes have kept the airline industry hungry for whatever revenue producing freight they can muster.

However, anti-competitive government regulation and a limit on the availability of cargo capacity on some routes makes it difficult for Atlantic area lobster shippers to effectively compete in some markets. He said his company does not generally sell to the U.S. west coast. Freight costs there from Canada are too high. Much lower rates are available through Boston or New York which have a multiplicity of air freight services across the continent, but it isn't economically practical to ship there from Atlantic Canada. In saying so, Mr. Risley says he isn't criticising the Canadian carriers. He does feel, however, that where the U.S. has lowered costs through deregulating its airline business, Canada has gone on building in higher costs through continued regulation.

With space to fill, Mr. Dossett says some U.S. airlines offer incentive rates on such cargo, thus having itself reduced some air cargo charges by as much as 50 percent to the west coast, he feels Air Canada is very price competitive.

Despite this Atlantic lobsters are getting to the west coast, if only in transit to such places as Tokyo and Hong Kong. The Orient is the next, new big market.

In fact, the trade is already well underway. After several years of intermittent shipments, Clearwater has been serving the market on a regular basis for the past year.

As development of the European market took time and effort to develop, so will the Orient. The big difficulty is transportation time. With the best connections, it generally takes about 36 hours for a lobster to get from Halifax to Hong Kong. This is well within the duration limit of the crustacean, if it is adequately packed and protected from temperature fluctuations enroute. But one lengthy delay or careless ground handling along the way could mean a very expensive insurance claim.

For this reason both the wholesale shippers and the airlines are going into the new market very cautiously. However, Air Canada's Gordon Dossett feels sure that given time, the Orient will be a substantial market. "I also believe that South America and the Middle East have considerable potential." Feelers have been put out by potential customers in the Middle East but Mr. Dossett thinks ground handling improvements will be needed before any substantial traffic develops there. "But as they have the bucks, we will do everything we can to see they get them."

Mr. Risley says developing new markets requires constant, personal involvement and supervision and a rapport between buyer and supplier. (Clearwater never sells through agents). It also requires a certain amount of local promotion for, believe it or not, there are still some people in the world who look a little strangely at the two clawed creature from Atlantic Canada, unaware of the sublime gastronomic delight they represent and even — shudder the thought — preferring the inferior, clawless creature unprepossessingly called a crayfish. AB

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The seawater system layout for Clearwater's plant at Clark's Harbour, Nova Scotia is illustrated in Figure 1.1. The mechanical room layout incorporating a heat pump is illustrated in Figure 1.2. (Figures located in pouch at the end of the report).

Implementation of the heat pump system will lead to other modifications within the plant. It is the intent of Clearwater Lobster Limited to commence a scientific research and testing program to identify the optimum water conditions for lobster handling. This is possible due to the economical heating and cooling capacity of the heat pump. A proposal describing the program for developement of long term dry land pound holding techniques in Clarks Harbour, Nova Scotia was submitted to Clearwater Lobster by Aquatic Systems Incorporated in March 1983. Requests for access to the information contained within the proposal or amplification of the company's long term plans should be addressed directly to Clearwater Lobster Limited.

4.0 OPTIMUM SIZE/PERFORMANCE OF THE HEAT PUMP

4.1 Design Parameters

A) Heat Source Temperature

- Twelve month cyclical variation between 0.5°C and 13°C

B) Seawater Temperature in the Plant

- Maintain a constant 2°C in the reservoir

C) Seawater Flow into the Plant

- 37.8 Litres/Second, twenty four hours a day, three hundred and sixty five days a year

D) Material Selection

- Non toxic to lobsters
- Relatively corrosion resistant

E) Heat Load

- Maximum obtainable from seawater flow

F) Cost

- Must reflect a reasonable payback period

G) Life Expectancy

- Maximum obtainable within reasonable equipment cost constraints
- Ideally 20 years

H) Operating Sophistication

- Existing plant personnel to be trained as operators

I) Maintenance

- Day to day by plant personnel with support available from manufacturer as required

J) Regulatory Standards

- Refrigeration Code CSA-B52-1977
- Nova Scotia Department of Labour Regulations

4.2 Design Options

The existing seawater system at Clearwater consists of four main components:

- Supply to the Reservoir
- 340,950 litre Reservoir
- Distribution/Return System between the Reservoir and Plant
- Gravity Return to the Ocean

Performance versus cost is the over-riding consideration in identifying the optimum heat pump installation for this application.

The first option involves the use of a single heat pump designed to take the maximum heat out of incoming seawater. Heat is economically available (COP greater than 1.5) for use from April to December, output fluctuates from 486 KW to 1622 KW. Capital cost of the unit (excluding engineering or support system) is estimated to be $689,000.00.

The second option involves the use of one plate heat

exchanger and two heat pumps of equal capacity (50% of maximum output). Heat is economically available throughout the year and output fluctuates from 380 KW to 615 KW. Capital cost of the main units (excluding engineering on support system) is estimated to be $285,000.00.

The third option involves the use of the same plate heat exchanger identified for the second option and one heat pump of 100% capacity. Heat is economically available throughout the year and output fluctuates from 380 KW to 615 KW. Capitol cost of the main units (excluding engineering and support systems) is estimated to be $239,000.00.

For demonstration purposes it is desirable to maintain costs at an acceptable level and extract heat year round. Consequently, option one is eliminated for both technical and economic reasons. Options two and three are both viable alternatives of approximately equal cost; however, several technical differences exist. The temperature range of the seawater leaving the heat pump fluctuates through a wider range in the third option and the control system and configurations in the second option are far more complex. Since the demonstration project is the first of its kind, simplicity will greatly aid in eliminating teething problems. For this reason and a slightly lower cost it was decided to

propose the third option as the best for this application.

4.2.1 Heat Pump Location In The Existing System

When identifying a location for a heat pump in the existing seawater system, it is important to ensure that a constant temperature throughout the plant is maintained. Evaluation of the system reveals that this can only be accomplished if the heat pump is put on either the supply line to the reservoir or the gravity return line to the ocean. If placed on the supply line, the temperature in the plant will vary according to the heat pump's output. On the gravity return line the temperature in the plant will be that of the ocean. The heat pump cannot be located on the distribution/return system to the plant due to the volume of water being circulated. There is a requirement to circulate 91.0 litres per second within the plant whereas the flow requirement into and out of the reservoir is 37.8 litres per second . If a heat pump was designed to operate with the maximum temperature differential (T.D.) available it would only operate at 100% capacity until the reservoir was cooled by the heat pump's discharge. This would occur very rapidly since replenishment from the ocean at 37.8 litres/second could not offset the greater volume of the distribution system return. Consequently the heat pump would only

operate at 100% capacity upon initial start up. The reservoir temperature would rapidly stabilize and the heat pump would operate almost continuously at 40% load or less. Operational efficiency over a twelve month period would be very low.

4.2.2 Equipment Configuration

The first option investigated consists of a single heat pump as illustrated in Figure 4.2.3. The unit is working with a maximum T.D. of 11°C (maximum incoming 13°C - reservoir 2°C). The energy extracted is supplied for heating purposes as 60°C freshwater. The size of the heat pump required is determined as follows:

$$Q = (4.15) \times (\text{litres/sec}) \times (\text{max T.D.}) \times (\text{specific heat})$$
$$= (4.15) \times (37.8) \times (11) \times (0.94)$$
$$= 1{,}622.0 \text{ KW}$$

The cost of the heat pump unit is approximately $689,000.00. It is estimated that the cost to install the complete system would be $835,000.00. Since this unit would only operate near or at the maximum T.D. for a very small portion of the year, it would be greatly oversized. Not only would the initial capital cost be exhorbitant, operating costs would reflect the inefficiences of operating almost continuously at partial load. The COP of this system below 3°C would

make it uneconomic to operate as is illustrated in figures 4.2.9 and 4.2.10.

To improve upon the first option and obtain a commercially viable system it was determined that it would be necessary to:

- Reduce the maximum T.D. and thereby the cost
- Obtain useable quantities of heat 12 months a year

The following scenario was determined to be the optimum system for maintaining a 2 °C temperature in the reservoir, while at the same time supplying useable heat year round. It differs from the first option in that a plate heat exchanger is used to stabilize the incoming seawater temperature and two heat pumps instead of one are used to provide heat when the seawater temperature drops below 3 °C.

To reduce the peak temperature during the summer months, the plate heat exchanger cools incoming seawater with the previously cooled seawater (at 2.6 °C) in the gravity return line to the ocean. The plate heat exchanger is designed with sufficient capacity to reduce the incoming seawater temperature to 4.8 °C which results in a maximum T.D. of 2.8 °C (4.8 °C- 2.0 °C) for the heat pump. This is a reduction in maximum temperature difference of 8.2 °C (11.0 °C- 2.8 °C). The

cooling capacity required in a system including a plate heat exchanger is:

$$Q = (4.15) \times (37.8 \text{ litres/sec}) \times (2.8\,^{\circ}C) \times (0.94)$$
$$= 412.8 \text{ KW}$$

To obtain useable heat year round, it was determined the optimum configuration would include two heat pumps each rated at 50% of the peak load to provide three flow path configurations which optimize heat output for the wide range of incoming seawater temperatures. The three system modes are illustrated in Figure 4.2.4 and described below.

MODE I Seawater Inlet Temperature Above 3.4 °C

The two heat pumps are connected in series on the supply line to the reservoir. When the temperature is above 4.8 °C the water passes through the plate heat exchanger first. Below 4.8 °C the plate heat exchanger is bypassed since precooling is not required.

MODE II Seawater Inlet Temperature 3.4 °C to 2.5 °C

The plate heat exchanger is bypassed since no precooling is required. The heat pumps are set up so that the incoming seawater needs to pass through only one unit to be lowered to the required 2 °C. The second

heat pump is then utilized to lower the seawater returning from the reservoir to the ocean to 1.2°C.

MODE III Seawater Inlet Temperature Below 2.5°C

The plate heat exchanger is bypassed. Incoming seawater also bypasses both heat pumps and goes directly into the reservoir. The heat pumps are connected in series on the gravity return line where they can further reduce the temperature by 2.8°C when operating at full load. The critical operating parameter is the freezing temperature of seawater which is -2°C. By limiting the discharge from the heat pumps to -1°C the system should be free of significant ice build-up. This will also alleviate any temperature differential in the immediate vicinity of the discharge since the relatively small volume of cold water being returned from the fish plant will be quickly dissipated in the ocean's vast reservoir.

The amount of heat available from this heat pump option is illustrated in Figure 4.2.5. On a constant demand basis the minimum heat available year round is 380 KW.

The cost of the heat exchanger and two heat pump units is estimated to be $285,000.00. The cost to install the total system is approximately $489,000.00.

Rationalization of the study objective and evaluation of the seawater system at Clearwater shows that it is possible to maintain the maximum potential cooling benefit even if the temperature in the reservoir is allowed to fluctuate between 2°C and 3.7°C. As a consequence, a third option is viable.

The plate heat exchanger is still required however instead of using two heat pumps of 50% capacity a single heat pump of 100% capacity can be utilized. The benefit is a lowering of the initial capital cost without a reduction in operational performance. Similar to the previous option, there are three modes of operation. They are illustrated in Figure 4.2.6 and described below.

MODE I Seawater Inlet Temperature Above 4.8°C

The incoming seawater passes through both the plate heat exchanger and the heat pump.

MODE II Seawater Inlet Temperature 4.8°C to 3.7°C

The plate heat exchanger is bypassed since no precooling is required. The incoming seawater passes directly through the heat pump.

MODE III Seawater Inlet Temperature Less Than 3.7 °C

The plate heat exchanger is again bypassed since no precooling is required. The incoming seawater goes directly into the reservoir. The discharge to the ocean through the gravity return line then passes through the heat pump.

Figure 4.2.7 illustrates the heat available from the third option. As with the second (optimum) option the maximum heat available on a constant demand basis is 380 KW. This parity in system performance is only achievable as a result of the variation in reservoir temperature between 2 °C and 3.7 °C. The available heat output of the same system but without allowing the temperature variation is illustrated in Figure 4.2.8. The maximum heat available on a constant demand basis is only 130 KW or 29% of the optimum.

The cost of the heat exchanger and heat pump for this system is $239,000.00. Total installed cost for the system is estimated to be $452,900.00 (see tables 6.1 & 6.1A).

In addition to decreasing initial capital costs the selection of the third option significantly reduces the

complexity of the control system needed to operate the system. This will not only increase the overall reliability of the system (mean time between breakdowns) but will also reduce the training time necessary to ensure the plants designated operating and maintenance personnel fully understand the new system.

4.3 Performance

To evaluate a thermodynamic cycle it is necessary to identify the ratio of useful output to input. Where mechanical energy is obtained from thermal energy, the ratio of useful output to input is always less than 1 and is called the "efficiency". In heat pump processes, heat can be upgraded from a low temperature to a high temperature by adding energy of a higher grade. The ratio of useful output to input in this case can be greater than 1 and is called the "Coefficient Of Performance".

The following information describes the expected performance of the system for Clearwater which includes a plate heat exchanger and a single heat pump.

Output

The useful heat output is equal to the total heat of

pump is installed. The power to operate the new seawater return pumps and cooling tower is offset by the reduction in the volume of water that must be supplied from the ocean to the reservoir. Therefore:

$$\text{Input} = \text{electricity to run compressors}$$
$$= 202.0 \text{ KW}$$

Coefficient of Performance (COP)

$$\text{COP} = \frac{\text{Output}}{\text{Input}}$$

$$= \frac{614.8 \text{ KW}}{202.0 \text{ KW}}$$

$$= 3.04$$

The expected COP of the heat pump is illustrated in Figure 4.2.10. The Figure indicates that the performance of the heat pump would drop to a COP of 2.64 at 62% and 12% of the maximum heat output of the heat pump.

This drop in performance is mainly attributed to the lower electric motor efficiencies at reduced loads, as illustrated in Figure 4.2.9.

The expected COP of the heat pump over the years

rejection of the heat pump. The heat pump in this application provides 60°C freshwater from the condenser. The heat of rejection is the sum of the energy available from the cooling in the evaporator and the energy required to compress the refrigerant.

Output = Heat of Rejection

Heat of Rejection = Evaporator Energy + Compressor Energy

Evaporator Energy = mechanical cooling requirement = Q

= (4.15)x(flowrate)x(T.D.)x(specific heat)

= (4.15)x(37.8)x(2.8)x(0.94)

= 412.8 KW

Compressor Energy = 2 x (power to run 125 HP motor)

= 2 x (101.0 KW)

= 202.0 KW

Output = 412.8 KW + 202.0 KW

= 614.8 KW

Input

The total power input required to operate the system is a measure of the additional electricity required to operate the existing seawater system after the heat

operation is illustrated in Figure 4.2.11. The heat pump will operate at its maximum efficiency for the majority of the year because of the demand for maximum cooling of the seawater supply to the lobster tanks.

5.0 EQUIPMENT SELECTION

In Section 4.2 of this report, the most suitable heat pump system for Clearwater Lobsters Limited was identified. Selection of individual components to make up the system requires investigation of many viable options with respect to the design parameters specified in Section 4.1.

The equipment that offers the least flexibility in choice is that which comes in direct contact with the existing seawater system. A schematic of the proposed seawater system including the heat pump is illustrated in Figure 5.1. The schematic of the existing seawater system is illustrated in Figure 5.7. There are four new components:

- plate heat exchanger
- seawater return pumps
- additional piping and valves
- heat pump evaporator

Selection of materials for these components must take into account the rate of corrosion due to seawater and the potential toxicity of certain metals to lobsters.

Lobsters cannot survive in seawater that has even traces of certain metals. In a study by D. G. Wilder

(1951) it was found that copper had the greatest toxicity followed by monel metal, zinc and lead. As a result of scientific testing it was determined that when exposed to these metals all lobsters die within the following time frames:

Copper - 18 hours
Monel - 139 hours
Zinc - 210 hours
Lead - 477 hours

Dr. Wilder's study also stated that iron, stainless steel, and aluminum are not toxic to lobsters.

Taking into consideration the restraints in material selection due to toxicity and the objective of the study which is to recover waste heat from seawater; it was determined that the metals suitable for heat exchange surfaces are:

- stainless steel
- titanium
- aluminum

The relative resistance to seawater corrosion for these metals is summarized in Appendix 'C'. Titanium is the best option.

In addition to metals, other materials suitable for use in the seawater system are glass and plastic. Plastic heat exchangers have not yet developed to the point where they are commercially available for industrial applications. Glass heat exchangers (see Appendix 'D') are commercially available however they are not suitable for this system.

5.1 Plate Heat Exchanger

The plate heat exchanger has been selected to cool 37.8 litres/second of incoming seawater from a peak of 13°C to 4.8°C when the outlet temperature in the return line from the reservoir is 2.6°C. The outlet temperature includes an allowance of 0.6°C for heat pickup from the building and solar gain during the summer months.

The plate heat exchanger was selected over a conventional shell and tube heat exchanger for the following reasons:

- there is a higher heat transfer co-efficient
- a smaller unit is required which results in a considerable reduction in the amount of titanium required.
- the individual plates can be separated for inspection and cleaning.

The plate heat exchanger will be constructed with a carbon steel frame, titanium plates and nitrile gaskets. The approach temperature will be 2.2 °C, there will be one hot side pass, one cold side pass and a pressure drop of 0.3515 KG/SQ CM

5.2 SEAWATER RETURN PUMPS

Seawater is supplied to the heat pump from an existing pump house located on the wharf beside the plant. There are two supply pumps (one standby) providing 37.8 litres/second of seawater to the main storage reservoir. The seawater is pumped from the reservoir into the plant, circulated and then then discharged back into the reservoir.

The water level in the reservoir is maintained through the use of an overflow standpipe and a gravity return line to the ocean. With the heat pump system, return pumps will be required to overcome the pressure drop in the plate heat exchanger or heat pump evaporator depending upon the mode of operation.

The return pumps will be selected to be compatible with the existing supply pumps in the plant. This will facilitate maintenance requirements. Two

pumps will be installed, each with sufficient capacity to handle full load requirements of 37.8 litres/second flow with a head of 0.7 KG/SQ CM. The pumps will be end-suction self-priming centrifugal type with all iron construction and a stainless steel shaft.

5.3 SEAWATER PIPING AND VALVES

The seawater piping system, currently in use at Clearwater is made of polyvinyl chloride (PVC) pipe and fittings. For compatibility the seawater piping to the heat pump and associated equipment will also be constructed of PVC.

The valves on the seawater system will be butterfly type with a PVC body and polypropylene (PP) disc. They will be installed with PVC flanges.

5.4 HEAT PUMP (see Figure 5.4)

The heat pump is made up of the following components.

5.4.1 Evaporator

There are two basic types of seawater evaporator

available for use with the proposed heat pump system.

A direct expansion evaporator has the refrigerant in the tubes and the seawater in the shell of the vessel. As illustrated in Figure 5.2, the seawater enters shell at one end of the vessel and is circuited around the tubes via baffles. It then exits the shell at the opposite end of the vessel. The refrigeration metering in a direct expansion evaporator is controlled by one or more thermal expansion valves. These valves control the liquid refrigerant input by sensing the temperature of the refrigerant suction gas leaving the vessel and entering the compressor.

A flooded refrigerant evaporator has the seawater in the tubes and the refrigerant in the shell of the vessel. As illustrated in Figure 5.3, the seawater enters the head of the heat exchanger and is circuited through the tubes. The number of passes the seawater makes through the evaporator is determined by the divisions of the vessel heads. The refrigeration metering in a flooded evaporator is controlled by a liquid level float switch that maintains the liquid refrigerant above the tube bundle. The float switch energizes the refrigerant liquid solenoid valve which lets liquid refrigerant into the vessel to compensate

for refrigerant that is boiled off and goes to the compressors.

The flooded refrigerant evaporator has been selected for this heat pump application for the following reasons:

- The metal selected for areas in contact with seawater is titanium, the direct expansion evaporator which has the seawater passing in the shell of the vessel would require titanium tubes, shell and titanium clad tubesheets. The manufacturing of this heat exchanger would be extremely costly.

- The seawater side of the heat exchanger should be accessible for inspection and cleaning if required. The flooded evaporator would only require unbolting the heads to provide access for tube inspection and cleanout. The seawater side of the direct expansion evaporator would not be accessible.

- The flooded evaporator has a liquid seperation vessel, which provides protection from liquid refrigerant carry-over to the compressors.

- The liquid metering control of the flooded evaporator is a simpler system to control and maintain, and presents fewer service

problems.

The evaporator is designed for a seawater flow rate of 37.8 litres/second and a maximum T.D. of 2.8 °C. The refrigerant capacity required is 412.8 KW at -2.7 °C suction and 61.6 °C discharge temperatures. Using R-12 as the refrigerant, the evaporator would be 600mm in diameter, 3600mm long with a liquid separation vessel (surge drum) mounted on top 600mm in diameter and 2400mm long. The evaporator has 408 - 75mm outside diameter tubes for a total heat transfer surface area of 89.1 square meters.

5.4.2 Refrigerant

As indicated above, the evaporator is selected based on the fact that R-12 is the refrigerant. R-12 (CCL_2F_2) was chosen for the following reasons:

- It is commonly available in the quantities that are required (905KG) and as shown in the following list it is comparatively inexpensive.

R-11	1.0
R-12	1.14
R-13 B1	6.4
R-22	2.0
R-114	2.0
R-502	2.95

- R-12 is suitable for low evaporating temperatures as well as high condensing temperatures.

- R-12 can readily be mixed with lubricating oil used in refrigeration machines and separation is fairly easy to accomplish.

- The pressures and operating temperatures are are much lower with R-12 than with R-22.

The refrigerant piping layout is illustrated in Figure 5.5.

5.4.3 Compressors

The total compressor capacity is selected to satisfy the design conditions of the evaporator. (412.8KW refrigeration capacity at -2.7°C suction and 61.6°C condensing temperatures).

The characteristics of the three basic types of heat pump compressor available for use in the heat pump are summarized in Appendix 'E'.

Two reciprocating type compressors are selected for this heat pump application for the following reasons:

- the compressor capacity requirement is within the normal operating range for open type reciprocating compressors

- the associated equipment required for rotary screw compressors is larger, more complex and more expensive

- the operational flexibility of two compressors provides greater efficiency for partial load conditions.

- two compressors will enable the system to remain 50% operational if a compressor breakdown occurs or if routine maintenance is required

- the design conditions selected are within the operating range of existing equipment

- reciprocating compressors are the least expensive option commercially available

Each compressor will be belt driven by a 125HP electric motor. The BHP at design conditions is 124.0 with a rotational speed of 1120 RPM.

5.4.4 Compressor Oil

The selection of the compressor lubricating oil is of prime importance in the heat pump system. In addition to providing lubrication in the compressor, it also reduces the wear on the cylinder walls by the piston rings. A small amount will continuously be carried into the system as a mist in the discharge hot gas.

The refrigerant oils used in heat pump applications are subjected to higher operating temperatures than would normally be encountered in a refrigeration system. The high temperature at the discharge valve of the compressor can catalyze the breakdown of oil and result in formation of carbon deposits. Over a period of time the compressor will be damaged and the lubricating

quality of the circulating oil will be greatly diminished.

Due to the severe operating conditions, a synthetic lubricant will be used in place of a conventional mineral based oil. The use of synthetic oils in actual field tests has proven their reliability in heat pump applications. They have excellent thermal/chemical stability with the halocarbon refrigerants and a low temperature fluidity which facilitates the return of oil from the flooded evaporator.

5.4.5 Compressor Motors

Two 125 HP totally enclosed fan cooled high efficiency motors are required to run the compressors. These were selected in lieu of standard open drip proof motors. A comparison of the two options is presented in Table 5.1.

5.4.6 Discharge Line Oil Separators

The discharge line oil separators remove the majority of the refrigerant oil entrained in the discharge vapour from the compressors. The separated oil is returned to the crankcase via a float valve.

5.4.7 Condenser

The refrigerant vapour from the compressor discharge is condensed to a liquid in the water-cooled condenser. The condenser removes the heat gained from the evaporator plus the heat of compression. The water flowrate required to remove this heat is 13.2 litres/second with an inlet temperature of 49 °C and outlet temperature of 60 °C.

The condenser is 400mm in diameter, 3600mm long and has a total heat of rejection of 614.8KW. The condenser contains 192 - 75mm outside diameter finned copper-nickel tubes.

5.4.8 High Pressure Receiver

The condensed liquid refrigerant from the water cooled condenser is stored in the high pressure receiver before being metered into the evaporator as the liquid level drops. The vessel is sized to contain the entire liquid refrigerant charge to facilitate servicing of other components.

The high pressure receiver is 500mm in diameter by 4800mm long and has a holding capacity of 905KG of R-12 at 80% full.

5.4.9 Oil Recovery Vessel

The oil recovery vessel and associated system is designed to remove refrigerant oil from the evaporator that was not removed in the discharge line oil separators. The oil in the evaporator will stratify at different levels in the liquid refrigerant. The oil is separated from the liquid refrigerant by continually draining small amounts of liquid refrigerant/oil mixture during compressor operation to the oil recovery vessel. The oil recovery vessel contains a 600 watt immersion heater that will boil off the refrigerant present. (The refrigerant vapour is returned to the liquid separation vessel on the evaporator).

The oil removed from the liquid refrigerant will accumulate until a float switch activates a hot gas transfer system to return the oil to the compressor crankcases.

5.4.10 Temperature Controls

When cooling is the dominant operating parameter, temperature control of the seawater leaving the evaporator will be maintained by a temperature activated suction pressure regulator with a sensor

in the leaving seawater line. The regulator is designed to modulate the suction pressure in the evaporator which will increase or decrease the water temperature difference through the evaporator as required. The compressors will automatically unload in steps as the suction load drops. The compressor will cycle off if there is no load. The suction pressure regulator will also be equipped with a low limit control to prevent suction pressure dropping to a point where evaporator freeze up may occur.

When heating is the dominant parameter, temperature control of the hot water leaving the condenser will be maintained by a temperature activated compressor unloader. As the temperature rises above the 60 °C design point, a reduced heating demand will be indicated and the compressors will automatically unload in steps to maintain the design outlet temperature. The heating system is equipped with a closed circuit evaporative cooler to ensure the hot water supply to the condenser does not exceed design temperatures.

The evaporative cooler would be utilized during periods when the heat pump is on cooling or heating mode and there is insufficient demand for the heat generated by the evaporator.

The inlet water temperature will be kept at design temperature by a three-way temperature activated water regulator on the hot water outlet of the condenser. The water regulator will have its sensor in the outlet hot water line so that when the water temperature rises above the 60°C set point the hot water will be circuited through the evaporative cooler and discharged into the condenser inlet.

5.4.11 - Electrical Control Panels

A schematic of the electrical layout is illustrated in Figure 5.6. The heat pump control panel mounted on the package will include the following components:

- main disconnect switch
- two 125HP auto-transformer starters for compressors
- control and timing relays as required
- pilot lights for each individual starter
- refrigerant suction pressure gauge
- refrigerant discharge pressure gauge
- running time meters for each compressor
- running ampere meters for each compressor

The mechanical room control panel will contain all

the starters and controls required for the remainder of the heat pump system. The following components are included:

- main disconnect switch
- hot water circulating pump starters
- seawater outlet pump starters
- closed circuit evaporative cooler two speed fan and circulating pump starters
- room exhaust fan starter
- control and timing relays as required
- pilot lights for each individual starter

5.4.12 - Safety Controls

The heat pump will be equipped with the following safety controls that will sound audible alarms and stop the heat pump if there is a possibility of damage to the unit.

A low refrigerant pressure cutout will prevent the compressors from operating at a lower pressure than is required for system operation. When the system pressure is below design conditions it indicates there is no load on the compressor. The low pressure switch is an automatic reset type, with a cutout point at a pressure below design, and a cut in point at a pressure above the design

point.

A high refrigerant pressure cutout will prevent the compressors from operating above the maximum design conditions. High pressure in the system could indicate a failure of the freshwater supply therefore manual reset will indicate that the cause of the failure should be investigated and corrected before the compressors are restarted.

A compressor oil failure switch will stop the compressor operation if the oil pressure falls below a pre-set point. The oil failure switch must be manually reset to ensure the operating problem is corrected before the compressors are restarted.

A high oil temperature switch will prevent the compressors from operating when the compressor oil temperature rises above the normal operating temperatures. One of the problems indicated by high oil temperature is a fresh water supply problem to the compressor oil cooler. A manual reset is incorporated to prevent compressor operation until the problem has been corrected.

Each comprssor will have a timer that prevents the simultaneous restarting of compressors in the event of a power failure. If the power supply is interrupted the timer will delay starting the first compressor by 30 seconds and the second

compressor by 60 seconds. This delay will prevent undue power drain on the plants electrical system when the power is restored.

The evaporator of the heat pump will be equipped with a freeze protection thermostat that will stop compressor operation if the temperature of the seawater drops below a preset level. The thermostat will require manual resetting to prevent potential damage to the evaporator.

The seawater inlet flowswitch will ensure the seawater supply pump is operating before the heat pump can start. Because of the remote location of the supply pumps from the mechanical room, an interlock from the starters of the supply pumps to that of the heat pump is not practical.

6.0- STATEMENT OF ECONOMIC VIABILITY

The capital cost to install the heat pump in Clearwater Lobster Limited's plant in Clarks Harbour, Nova Scotia is estimated to be $452,900.00. A breakdown of this cost is illustrated in Table 6.1.

The annual operating cost for the heat pump is estimated to be $71,800.00. A breakdown of this cost is illustrated in Table 6.2.

The potential areas of benefit to Clearwater Lobster Limited from installation of the heat pump are described in Sections 6.1 and 6.2. Integrating a heat pump into their existing operation not only provides a cheap source of heat but also supplies valuable cold seawater. Part of the heat will be used within the plant immediately to replace the output of the existing oil-fired furnace. The rest of the heat will be used when the installation of a new warm seawater holding system is completed. The heat pump is the principal component of the new system. The actual value of the cold water will ultimately be determined from future analysis of the plant's operation and scientific biological evaluation. For the purpose of this study the net monetary value of the benefits to Clearwater on an annual basis are identified as follows (based on the buying power of the 1983 dollar).

Immediate Savings (1-3 years)

heat = $ 25,000.00
cold water = $175,000.00
total = $200,000.00

Following the demonstration of the reliability of the output capability of the heat pump, Clearwater Lobsters Limited will isolate a section of their dryland pound and heat the seawater within this section to approximately 15.5°C. This will increase the metabolism of moulting lobsters which in turn will decrease the time it takes for them to return to a high quality market product. The annual heating requirement to warm the necessary flow of seawater during the trial period will be 1,843,704 KWh, which would cost approximately $78,493.00 using conventional fuel oil fired boilers. Once the optimum warm water temperature is identified the total heat output of the heat pump will be used for commercial benefit. The current value of the heat is $206,610.00.

A titanium plate heat exchanger will be required to transfer heat from the heat pump condenser water to the incoming seawater at an additional capital cost of $19,000.00. (See heated seawater section for calculations).

Annual savings incorporating the the warm seawater section will be:

heat = $206,610.00
cold water = $175,000.00
total = $381,610.00

The easiest method of establishing the economic credibility of the project is calculation of the simple payback period. While this very basic method of analysis does not take into account the cost of money, the inflation rate or methods of funding, it has proven to be a very accurate initial estimate in heat recovery projects throughout the world. Increasing costs for conventional forms of energy and the value of the money saved, normally balances carrying charges on initial capital and design expenditures.

Immediate payback:

$$\text{Payback period} = \frac{\$452,900.00}{\$200,000.00 - \$\ 71,800.00} = 3.53 \text{ years}$$

Immediate payback incorporating warm seawater savings:

$$\text{Payback period} = \frac{\$471,900.00}{\$381,610.00 - \$\ 71,800.00} = 1.52 \text{ years}$$

The maximum potential output of the heat pump is described in Section 7. The heat output will be immediately utilized to supply heating and hot water requirements at Clearwater Lobster and Stoddard Fisheries, and subsequentally, to warm seawater in a section of the dryland pound. The actual utilization of heat output is described in the following section.

6.1- UTILIZATION OF HEAT OUTPUT

The hot water from the heat pump will be used to replace or supplement the following oil fired equipment at Clearwater Lobsters Ltd. and at Stoddard Fisheries Ltd. an adjacent fish processing plant.

CLEARWATER LOBSTER LTD.

The clearwater plant has the following equipment:

One - Bryan flexi-tube steam boiler with a capacity of 615.3 KW of low pressure steam.

The boiler is used for cooking lobsters on a year-round basis, and to heat the processing areas and office space in the plant.

The hot water from the heat pump would be used to preheat cooking water to 55°C.

The processing areas and office heaters would have to be changed to hot water type.

Estimated fuel oil saving = $15,000.00

STODDARD FISHERIES LTD.

Stoddard Fisheries process and dry fish for local and export markets. The plant has the following equipment:

Fish Driers

2 - Forced air furnances (one for each drier) capacity of approximately 58.6 KW each.

Heating Building

2 - Forced air furnances each with a capacity of 58.6 KW

Total plant capacity = 235.6 KW.

The fish driers are currently used when weather conditions do not permit drying fish outdoors. The plant operators have indicated that if an inexpensive alternate form of heat were available, the driers would be used continuously with a possibility of additional driers to increase capacity.

The existing fish driers and plant heating system would require the addition of hot water coils that would be supplied by hot water lines from the mechanical room at Clearwater Lobster.

Estimated fuel oil saving = $10,000.00.

The hot water piping schematic proposed for Clearwater Lobster and Stoddard Fisheries is illustrated in Figure 6.1.

HEATED SEAWATER- CLEARWATER LOBSTER LTD.

The objective of this warm seawater will be to stimulate the molting of the lobster and subsequently the hardening of the new shell to produce a marketable product.

The required warm seawater flowrate is 6.3 litres/sec. The heating requirements to raise the temperature from a minimum of 0.5 C to 15.5 C are:

Q = (4.15) x (litres/Sec.) x (Max T.D.) x (Specific Heat)

= (4.15) x (6.3) x (15.5°C - 0.5°C) x (.94)

= 368.6 KW

The above figure is the maximum required heat input for the lowest seawater temperature expected.

The seawater varies from 0.5°C to 13.0°C (See Figure 4.2.1 for yearly temperature profile.)

Total yearly heat input based on
monthly average seawater temperature
to warm seawater to 15.5°C = 1,843,704 KWh

1,843,704 KWh x 3.6 MJ/KWh = 6,637,334 MJ

Eqivalent Cost of Heating with Fuel Oil

Actual heating value of fuel oil
assuming 70% furnance efficiency = 28.75 MJ/L

Equivalent fuel oil used:

$$\frac{6,637,334 \text{ MJ}}{28.75 \text{ MJ/L}} = 230,864 \text{ Litre}$$

Fuel Oil Cost at $.34/Litre:

230,864 Litres x $.34/Litre = $78,493.00

Therefore to heat the sewawater flow to 15.5°C year round with a conventional oil fired boiler would cost $78,493.00.

The piping schematic of the warm seawater system is illustrated in Fig. 6.2. A plate heat exchanger made of titanium would be required to transfer the heat from the hot water coming from the heat pump condenser to the incoming seawater.

6.2 - VALUE OF MAINTAINING SEAWATER IN SYSTEM AT 2°C

As explained in APPENDIX "B" there is a definite advantage to maintaining a constant low seawater temperature in the plant throughout the year.No documented case histories exist that accurately identify a monetary value of the savings to be expected for specific reduction in temperature; however, industry experience is able to identify the following areas losses occur that are directly related to high temperature.

Mortality- Cannabalism

During the warm summer months there is approximately a 4% loss of healthy lobsters due to increased activity. Lowering the temperature is expected to reduce the loss to 1%.

EXPECTED SAVINGS = $42,000.00

Mortality- Disease

Gaffkemia is fatal to lobsters and is highly contageous, however it remains dormant if the lobster is stored in low temperature seawater. A single diseased lobster can result in the loss of the entire inventory being held . Gaffkemia does not affect the quality of cooked lobster meat, nor is it harmfull to humans. Consequently, early diagnosis allows the lobsters to be processed prior to spoilage occuring.Monetary losses are the difference in value between

a top quality live product available for export and a standard packaged commodity for local consumption.

EXPECTED SAVINGS = ? (zero to $150,000.00)

Improved Quality- Inventory Life

Prevention of moulting would allow Canadian lobsters to be held in a longer inventory cycle. This would eliminate the requirement for Clearwater to source low quality lobster in the United States in the fall. Storage and transportation losses amount to between 13,600 and 34,000 kilograms.

EXPECTED SAVINGS = $120,000 TO $300,000

Improved Quality- Shrinkage

Storage in low temperature water reduces the lobsters metabolism. Since lobsters in storage are not fed the rate at which they shrink is reduced.

7.0 ENERGY SAVINGS

MAXIMUM ANNUAL ENERGY OUTPUT OF HEAT PUMP

Energy Available

(6336HRS)x(100%Capacity)x(614.8 KW)	= 3,895,372 KWh
(528HRS)x(80%Capacity)x(614.8 KW)	= 259,691 KWh
(1896HRS)x(60%Capacity)x(614.8KW)	= 697,920 KWh
Total	= 4,852,983 KWh
(4,852,983 KWh)x(3.6MJ/KWh)	= 17,470,739 MJ

To determine a monetary value for this heat it is necessary to identify the cost of supplying an equivalent amount of energy by the most cost effective alternative. In Nova Scotia number 2 fuel oil is currently the cheapest option available to Clearwater Lobster Limited.

Equivalent Cost of Fuel Oil

Theoretical heating value of fuel oil = 41.0 MJ/L

Actual heating value assuming 70% furnace efficiency: = 28.75 MJ/L

Equivalent fuel oil used (total recoverable)

$$\frac{17,470,739 \text{ MJ}}{28.75 \text{ MJ/L}} = 607,678 \text{ Litres}$$

Equivalent fuel oil used (constant demand)

$$\frac{(8760 \text{ hrs}) \times (60\%) \times (614.8\text{KW}) \times (3.6\text{MJ/KWh})}{28.75 \text{ MJ/L}} = 404{,}626 \text{ Litre}$$

As of 01 Feb 1983 fuel oil cost $0.34/Litre in Nova Scotia

(607,678 Litres) x ($0.34/Litre) = $206,610.00

(404,626 Litres) x ($0.34/Litre) = $137,573.00

During the period of April 1 to December 20 the heat pump is required to operate at 100% capacity because of the cooling load. The heat output available above the minimum heat output would be 40% of the total heating capacity during this period.

(6336HRS) x (614.8KW) x (3.6MJ/KWh) x (40%) = 5,609,337 MJ

This heat output could be utilized for inplant processing during this period over and above the 60% of maximum heat output that is available year round.

$$\frac{(5{,}609{,}337 \text{ MJ})}{(28.75 \text{ MJ/L})} \times (\$0.34/\text{Litre}) = \$66{,}336.00$$

COMPARISION OF ENERGY SUPPLY COSTS

Typical Oil Fired Boiler

Theoretical heating value of fuel oil = 41.0 MJ/L

Actual heating value assuming 70% furnace efficiency = 28.75 MJ/L

$$\frac{28.75\ \text{MJ/L}}{3.6\ \text{MJ/KWh}} = 7.98\ \text{KWh/L}$$

Cost per KWh at $0.34/Litre

$$\frac{\$0.34/\text{Litre}}{7.98\text{KWh/Litre}} = \$.043/\text{KWh}$$

Heat Pump

Yearly maximum operating costs based on $.04/KWh = $71,800.00

Yearly maximum heat output = 4,852,982 KWh

Cost per KWh

$$\frac{\$71,800.00}{4,852,983\text{KWh}} = \$.015/\text{KWh}$$

For comparative purposes within the Canadian fish processing industry the most important statistic from the study of Clearwater Lobsters Limited is the ratio of heat that can be economically recovered from a constant flow of seawater.

The design parameters of the heat pump are as follows:

Seawater Flowrate : 37.8 Litre/sec (136,080 Litre/hr)

Ocean Temperature : 0.5 C to 13 C

Hot Water Output Temperature : 60 C

Maximum Heat Output : 614.8 KW
(in one hour)

Maximum Heat Output : 5,385,648 KW
(in one year)

The maximum heat recovered is the total heat extracted from the seawater over the period of one year. Establishing an economic value for this heat is accomplished by equating the energy value of the seawater to the cost of supplying an equivalent amount of energy with conventional hydrocarbon fuels.

Energy Per Litre of Seawater

$$\frac{614.8 \text{ KW/HR}}{136{,}080 \text{ Litre/Hr}} = 0.0045 \text{ KW/Litre}$$

From compilation of information from various sources it is estimated that there are approximately 520 saltwater fishplants distributed throughout Nova Scotia, New Brunswick, Newfoundland, Prince Edward Island, Quebec and British Columbia. In a report prepared in 1980 for the Nova Scotia Department of the Environment, by A. Orlic and Associates, it was shown that an average fishplant currently uses 1,247,995 litres of seawater per year; however, they have a pumping capacity of 68 litre/sec. Consequently the average fishplant could pump 2,144,448,000 litres of seawater per year if they operated a heat pump. On a nation wide basis the quantity of energy that is economically recoverable with existing equipment is determined as

follows:

Total KW = (Plants)x(Water Used)x(KW/Litre)

For Maximum Output

= (520)x(2,144,448,000 L/Yr)x(0.0045 KW/L)

= 5,015,058,285 KW/Year

= 18,054,000,000 MJ

In Atlantic Canada where the majority of Canadian fish plants are located, the most common fuel is imported number 2 fuel oil. The theoretical heating capacity of the fuel is 41.0 MJ/L; however assuming 70% efficiency in combustion is achieved, the actual heat available from one litre of oil is 28.75 MJ.

$$\frac{18,054,000,000 \text{ MJ}}{28.75 \text{ MJ/L}} = 627,972,515 \text{ litres of Oil}$$

The current cost of oil is $0.34/litre therefore the value of the oil is $213,510,655.00.

The fish processing industry is only one small segment of Canadian society that currently uses or has access to massive volumes of seawater. Identifying these potential users would probably show that the savings in fishplants are only the tip of the iceburg for equating the potential

benefits from ocean source heat pumps on Canada's national energy picture.

8.0 RESEARCH AND DEVELOPMENT REQUIREMENTS

From the work carried out on the project to date, several areas of investigation could be persued that would potentially be very beneficial to the utilization of ocean source heat pumps in many different applications. As with all industrial heat pump applications any improvements in compression efficiency would be valuable. For the ocean environment, any developments that would increase resistance to corrosion and ultimately reliability are of paramount importance. Durability can be achieved with existing equipment but it is very costly.

Most research and development ideas will come from experience gained in the commissioning and monitoring of the pilot plant. Presented below are some general areas for improvement that were identified during pre-engineering phase of the project:

- Single stage reciprocating compressors offer the cheapest alternative in low temperature applications below 150HP. With existing equipment, operation is restricted to a 70 C temperature differential between the suction and discharge ports. The heat pump's output is therefore limited to approximately 60^{o}C unless a more expensive multi-stage unit is used. Improving the design to permit output

temperatures above 60°C would potentially expand their use into applications which are currently economically marginal.

- Plastic coatings are currently used on heat exchange equipment in the chemical processing industry. Use of very thin coatings on the tubes in evaporators may be more cost effective than using expensive metals such as titanium.

- Development of microprocessor controls similar to those which are starting to be used for refrigeration systems. Equipment does exist that could be applied to heat pumps; however, it is very expensive to apply general purpose equipment to a relatively small application. Excess capacity and unrequired flexibility make the initial capital costs prohibitive.

- Technological improvements in the design of glass heat exchangers to sustain higher pressures would make them very attractive for use in the ocean environment.

- To develop the total potential of the Canadian market it will be necessary to identify all industries and commercial establishments

currently using seawater.

- The use of computer modelling to obtain the optimum component sizing vs. costs, would be of great benifit in the design of heat pump systems.

9.0 OPERATIONAL MANAGEMENT

9.1 Operator Skills

Operation of the heat pump system proposed for Clearwater Lobsters Limited will fall under the regulations of the Nova Scotia Department of Labour; Stationary Engineers Act 1980, chapter 18.

The heat pump will be classified as a "Refrigeration Plant" which is defined as "an installation comprised of one or more refrigeration compressors and the equipment used therewith for compressing and liquefying and evaporating a refrigerant and over fifty motive horse power".

There will be two heat pump compressors in the system, each rated at 125 HP. Consequently the plant will require an operator on staff in possession of a second class refrigeration ticket. This is defined in paragraph 39 of the act as follows, "The holder of a certificate stationary engineer (refrigeration plant) second class may act as chief stationary engineer in any refrigerator plant covered by the act and not exceeding 600 motive horse power."

The requirements for certification as a second class-refrigerator operator are defined by the act as

follows:

- The candidate must be at least eighteen years of age.
- The education requirement must be met: completion of grade ten in a Nova Scotia high school or its equivalent.
- The practical experience requirement must be fulfilled: twelve months in a plant over twenty-five motive horsepower.
- The candidate must pass the examination for second-class refrigerator plant operators.

The Clearwater plant at Clark's Harbour currently employs maintenance personnel who meet most of the above criteria.

A representative of the stationary engineering branch of the Nova Scotia Department of Labour has indicated that existing maintenance staff will qualify for a second class certification examination after obtaining on the job experience.

Cleawater's maintenance personnel will be directly involved from the commencement of installation. Representatives from IPE and the heat pump manafacturer will ensure they are throughly familiarized with the systems operation.

Routine inspection, maintenance and defect rectification will be carried out by plant personnel. If a more complex situation arises, the heat pump manufacturer will be called in. The heat pump will be covered by at least a one year manafacturer's warranty, which will include material defects and operating problems which are a result of equipment failure.

9.2 Maintenance Requirements

Seawater Evaporator

The evaporator may require periodic cleaning of the seawater side. The interval between cleanings will have to be determined from observations during the initial monitoring period. The actual cleaning procedure will involve removal of the cast iron heads and use of a tube brush.

Leaky tubes will be plugged until such time as it is convenient for the operator to isolate the unit for an extended period of time. Tubes will only be replaced when there have been a sufficient number plugged to significantly reduce the unit's heat transfer characteristics. During the replacement operation the refrigerant will be transfered and stored in the high pressure receiver.

The presence of a refrigerant leak will be evident from a drop in the level in the high pressure receiver. The level will be checked daily by the operator.

Hot Water Condenser

This unit will require very little maintenance. Operating in a closed loop hot water system eliminates potential fouling problems as long as the water is conditioned properly.

The heads of the condenser can be easily removed during inspections. The tubes are made of a copper-nickle alloy which is extremely resistant to corrosion.

Plate Heat Exchanger

The flow characteristics of the plate heat exchanger provide very good resistance to fouling(approximately 20% of that expected in shell and tube designs). With titanium being very resistant to seawater corrosion, the intervals between openings should be reasonably lengthy. When cleaning or an inspection is required disassembly is relatively easy.

Compressors

These components will require the utmost attention to maintenance details. The almost non-stop operation puts a very heavy strain on many different areas and is one of the primary reason that so many pressure and temperature switches are incorporated into the design.

The oil level of each compressor will be checked twice daily. Temperatures will also be noted to detect operating irregularities prior to the point at which automatic shutdown will occur. An annual inspection of the compressors by a certified refrigeration mechanic will be required to ascertain if excessive wear necessitates the replacement of components which have exceeded acceptable tolerances.

Spare compressor parts carried on site would not be required with the exception of a shaft seal. The normal replacement parts are stock Dartmouth, if a major breakdown occurred parts are stock Toronto.

10.0 MONITORING PROGRAM

Acceptance of the new technology and recognition of growth potential by the operators of the demonstration plant is as important as the precise calculation of the monetary benefits immediately available. It is from the ideas and experience of the day to day operators and maintenance personnel that potentially significant areas of development will be identified. Improvement of existing products and innovative new applications for theoretical principles will assist the growth of a new industial heat pump industry.

A schematic of the heat pump system indicating the proposed layout of 38 fixed monitoring points is illustrated in Figure 10.1. As well as providing data for economic analysis, these points will verify individual component operation when fault finding, carrying out maintenance routines or testing the system after the rectification of defects. Three seperate sub-systems are being monitored:

- Seawater Distribution
- Hot Water Distribution
- Heat Pump (including refrigerant cycle)

Identification of the monitoring points by sub-system is included in Tables 10.1 through 10.3.

The results from the monitoring program will identify the actual operating performance versus the optimum design expectations. The principle areas of evaluation will include:

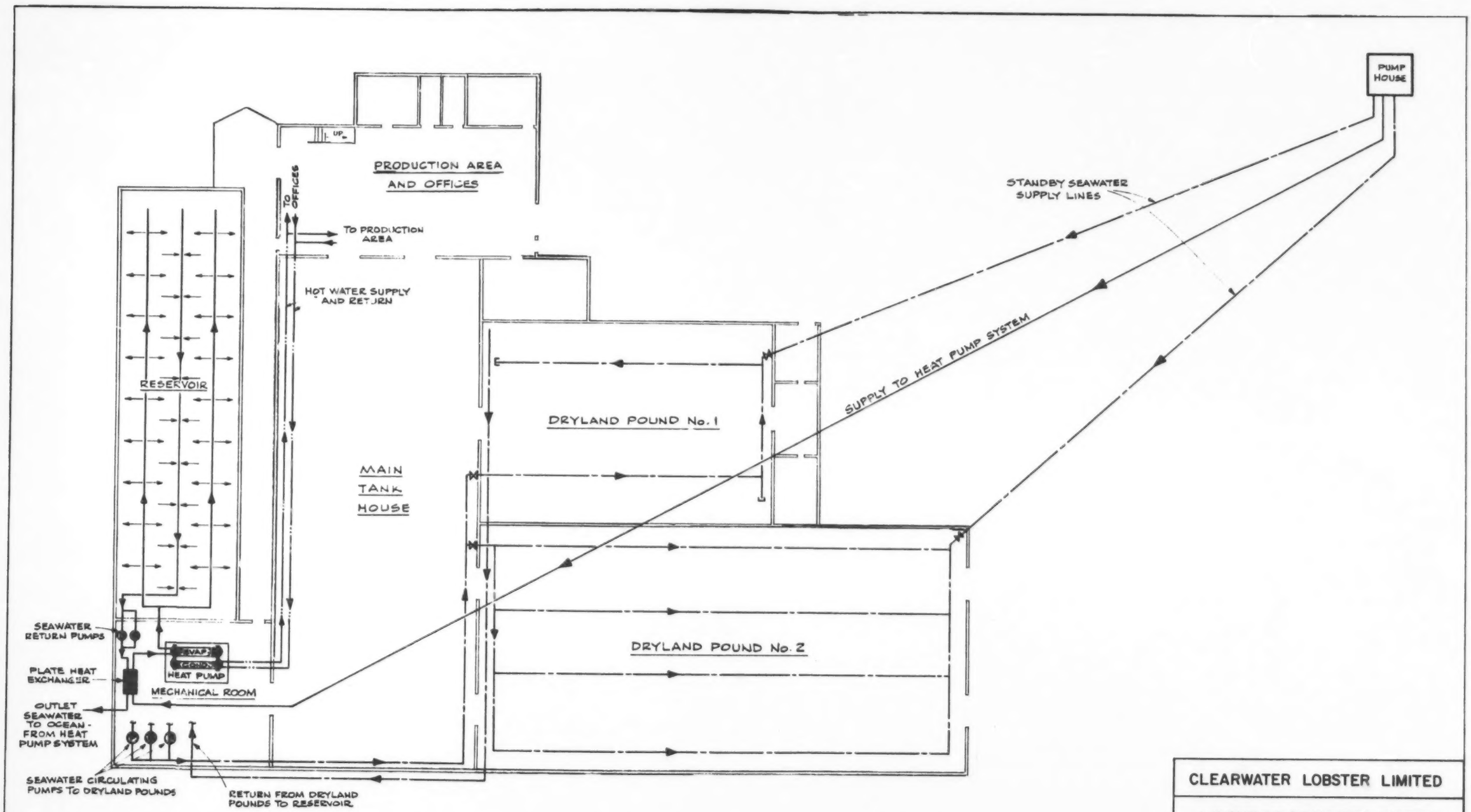
- Heat Output
- Electrical Consumption
- Ease of Operation
- Training Requirements
- Maintenance Requirements
- Reliability
- Personnel Acceptance
- Affects of Environmental Variables

It is recommended that an initial monitoring period of 18 Months be undertaken once the heat pump is installed and commissioned. This will permit baseline data to be collected for the first 12 Months and comparitive performance data to be established for the following 6 Months. Evaluation of the data will identify the requirements for longer term monitorihg and performance evaluation which may be econmically carried out remotely using state of the art computer-based systems.

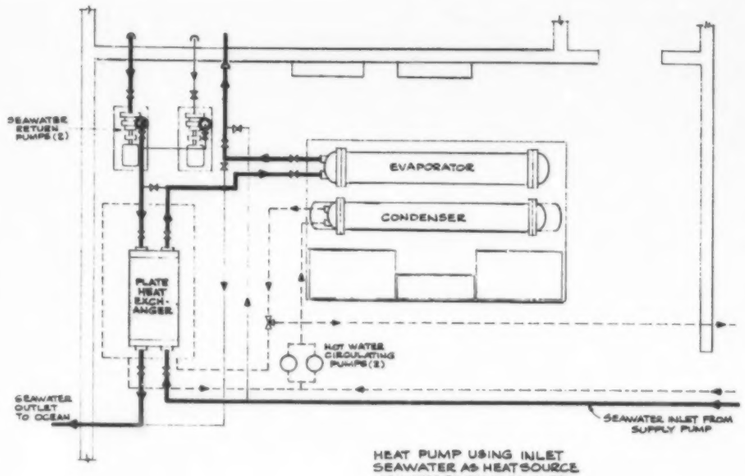
Installation of on-site direct reading monitoring equipment

with the heat pump is required to evaluate individual component performance during the start-up and trials period. Using this installed equipment, the cost to monitor the heat pump installation at clearwater Lobsters Limited is estimated to be $63,550.00. The actual scope of the evaluation program will vary depending upon the specific requirements of NRC and experience gained during the commissioning phase. A breakdown of potential manpower allocations and disbursements is illustrated in Table 10.4.

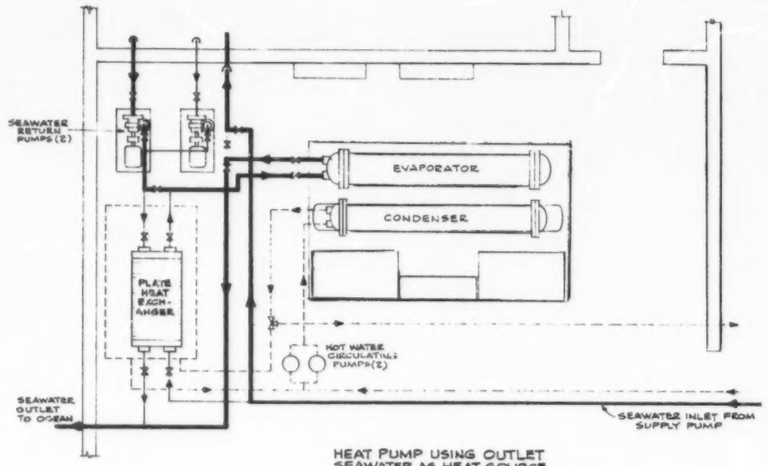
FIGURES



CLEARWATER LOBSTER LIMITED	
LAYOUT OF SEAWATER SYSTEM	
INTERPROVINCIAL ENGINEERING LTD.	FIGURE No. 1.1

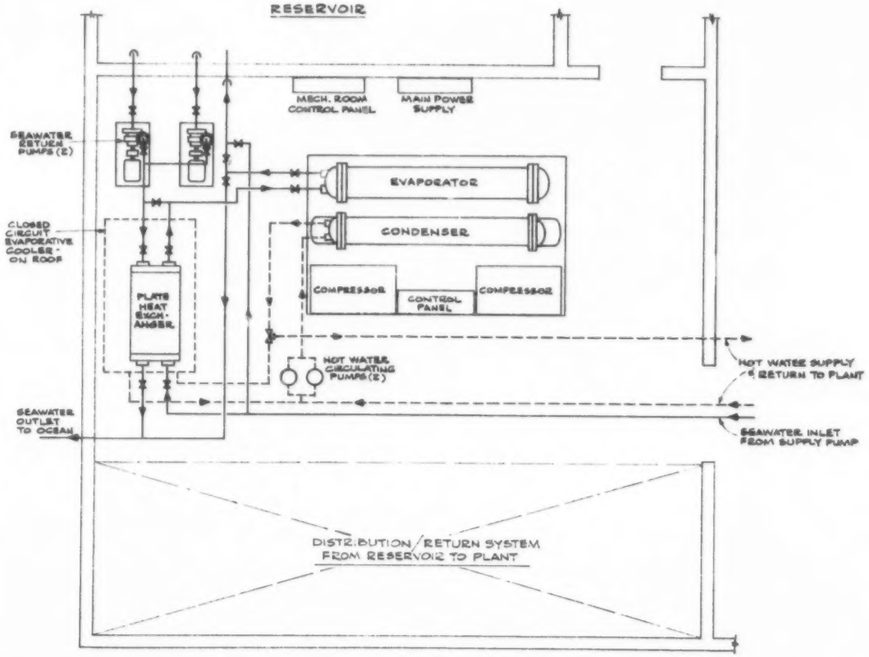


HEAT PUMP USING INLET SEAWATER AS HEAT SOURCE
- SEAWATER TEMPERATURE > 3·7°C.



HEAT PUMP USING OUTLET SEAWATER AS HEAT SOURCE
- SEAWATER TEMPERATURE < 3·7°C.

— MODES OF OPERATION —

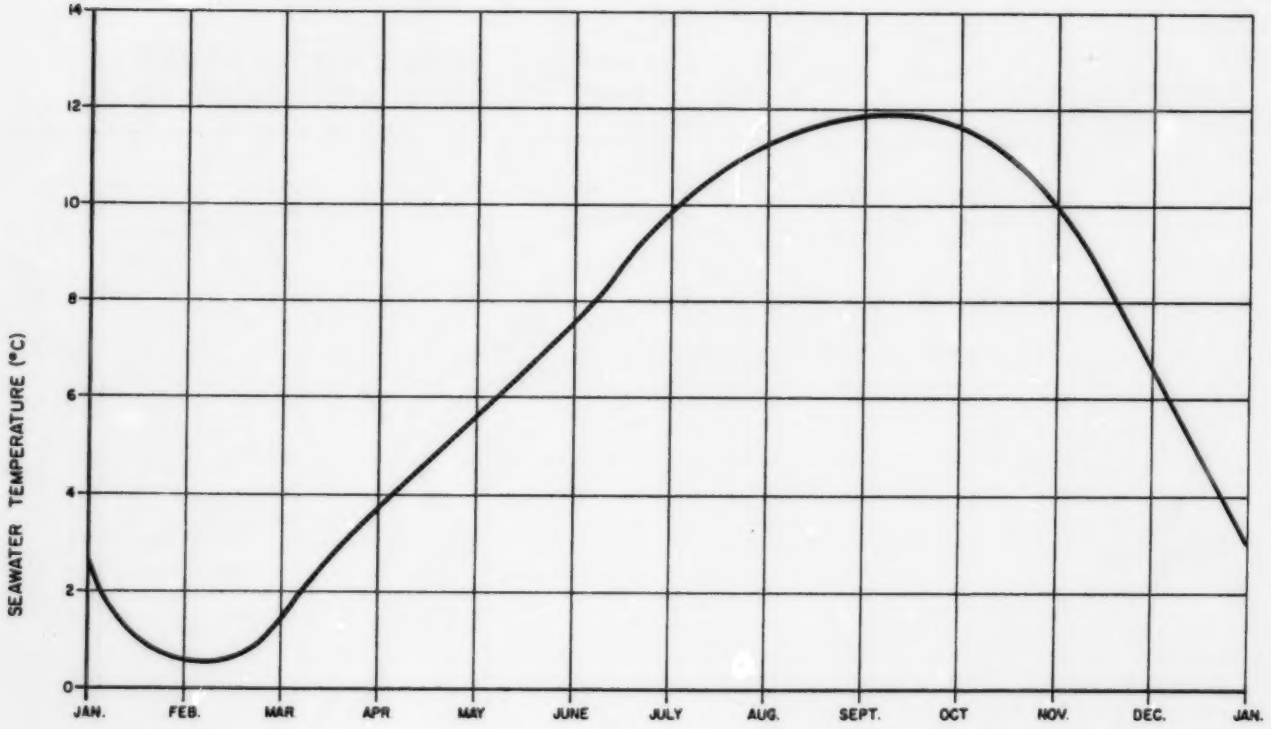


PLAN
N.T.S.

CLEARWATER LOBSTER LIMITED

MECHANICAL ROOM LAYOUT

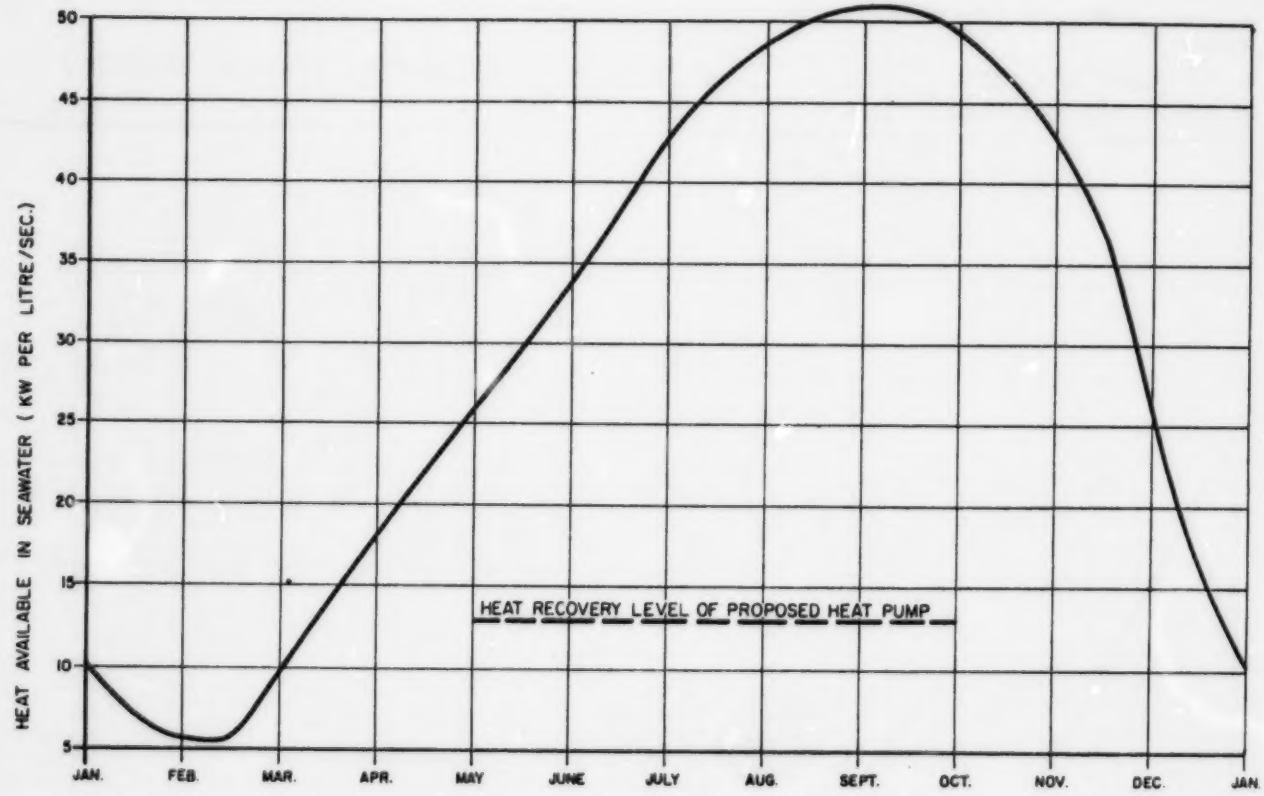
FIGURE No. 1.2



AVERAGE YEARLY SEAWATER TEMPERATURES

CLEARWATER LOBSTER
CLARK'S HARBOUR

FIGURE 4·2·1

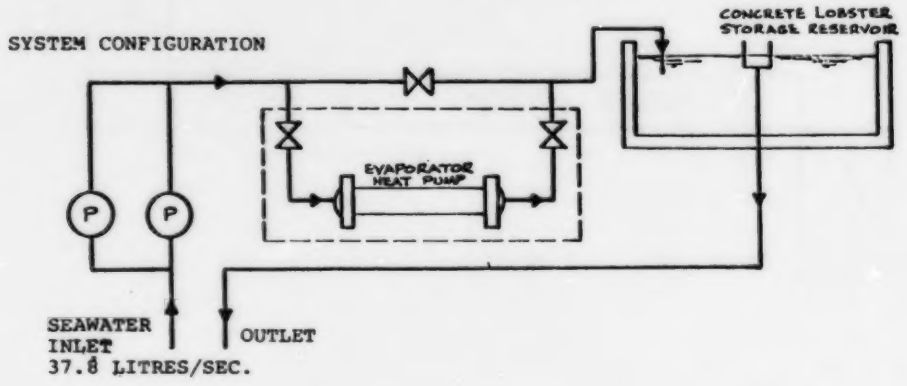


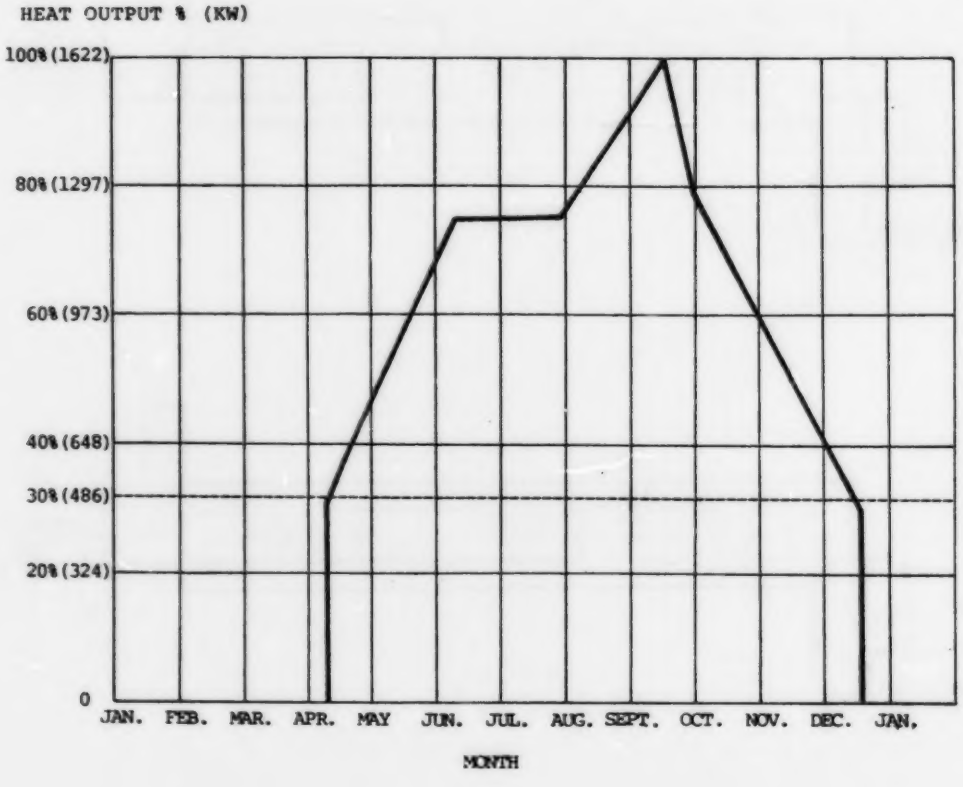
MAXIMUM HEAT AVAILABLE FROM SEAWATER
(BASED ON -1·0°C LEAVING SEAWATER TEMPERATURE)

CLEARWATER LOBSTER
CLARK'S HARBOUR

FIGURE 4·2·2

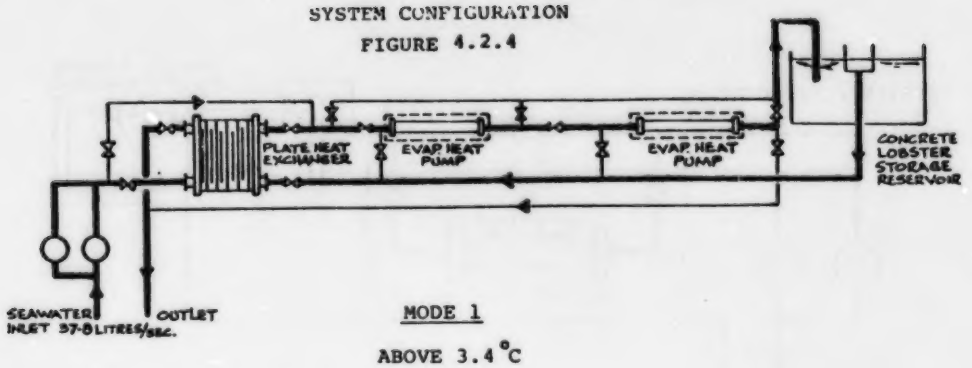
FIGURE 4.2.3


SYSTEM CONFIGURATION
CONCRETE LOBSTER STORAGE RESERVOIR
EVAPORATOR HEAT PUMP
P
P
SEAWATER INLET
37.8 LITRES/SEC.
OUTLET


HEAT OUTPUT % (KW)
100% (1622)
80% (1297)
60% (973)
40% (648)
30% (486)
20% (324)
0
JAN.
FEB.
MAR.
APR.
MAY
JUN.
JUL.
AUG.
SEPT.
OCT.
NOV.
DEC.
JAN.
MONTH

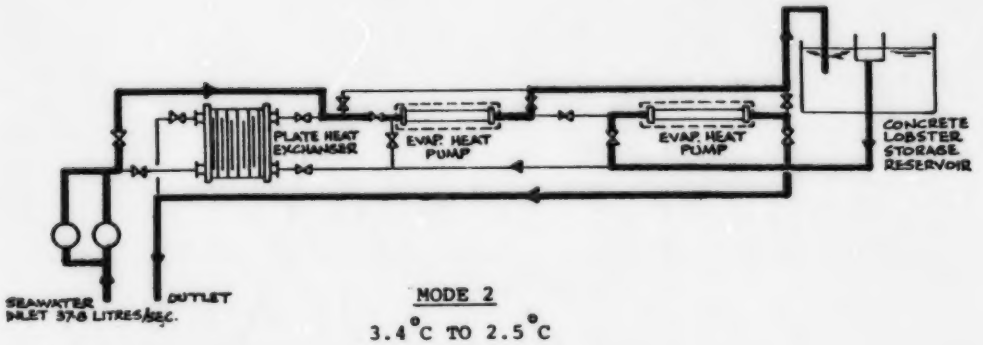
SYSTEM CONFIGURATION

FIGURE 4.2.4



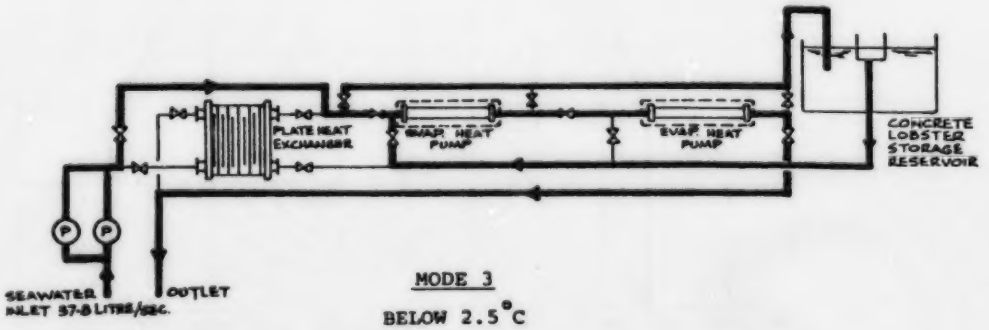
MODE 1

ABOVE 3.4 °C



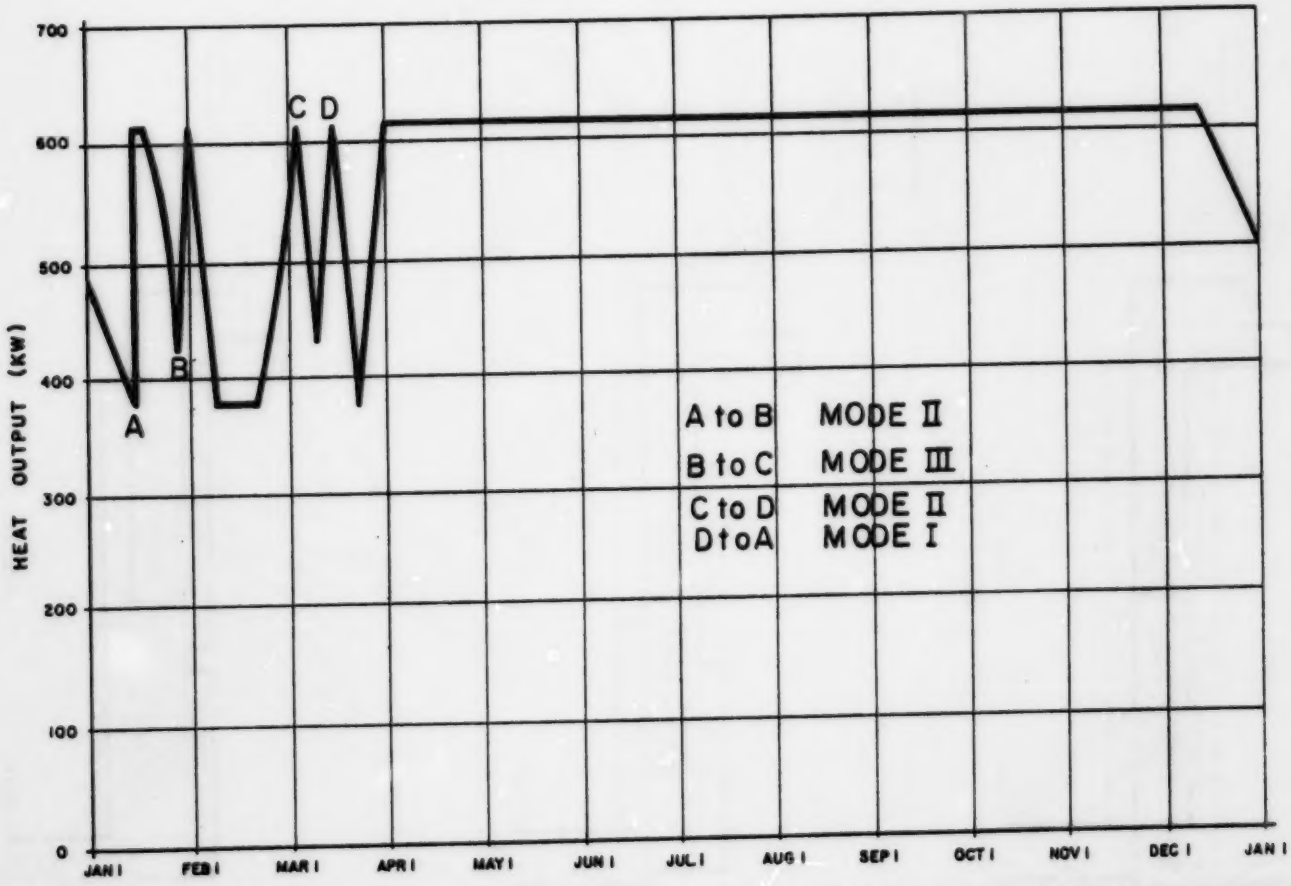
MODE 2

3.4 °C TO 2.5 °C



MODE 3

BELOW 2.5 °C

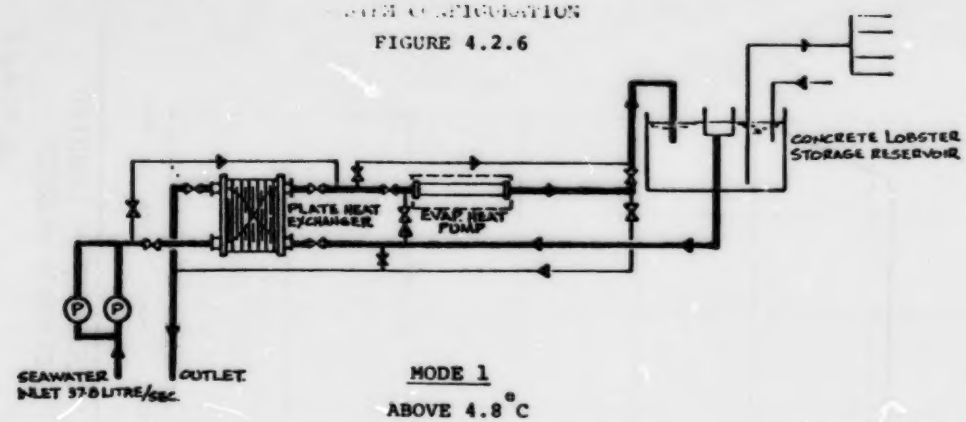


HEAT OUTPUT OF TWO HEAT PUMPS
(SEAWATER INLET TO TANKS 2°C TO 2·5°C)

CLEARWATER LOBSTER
CLARK'S HARBOUR

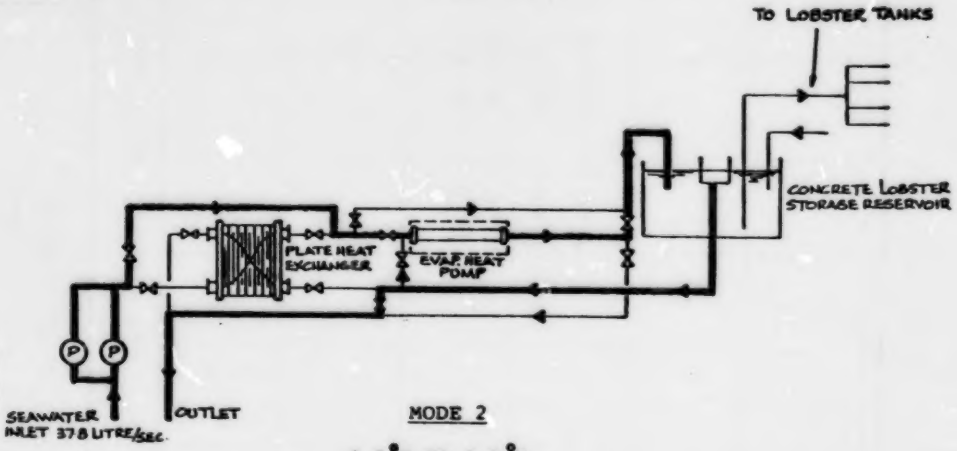
FIGURE 4·2·5

FIGURE 4.2.6



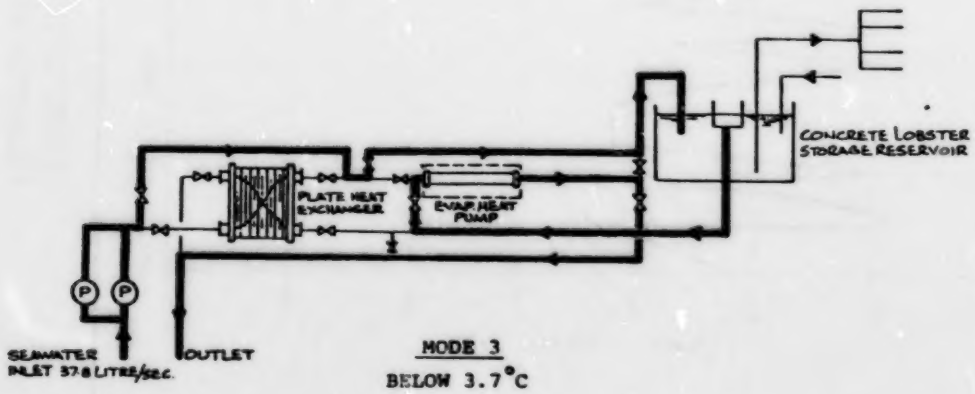
MODE 1

ABOVE 4.8 °C



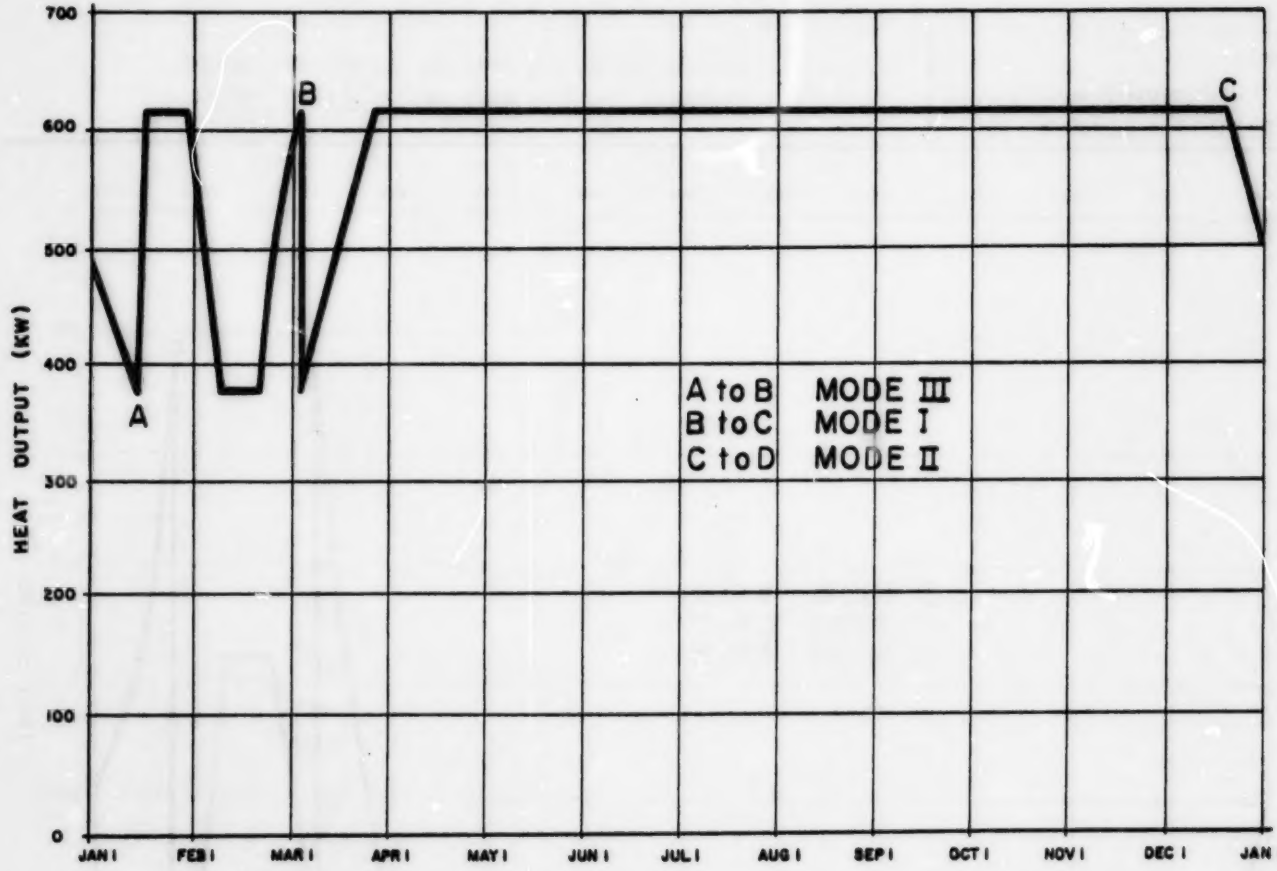
MODE 2

4.8 °C TO 3.7 °C



MODE 3

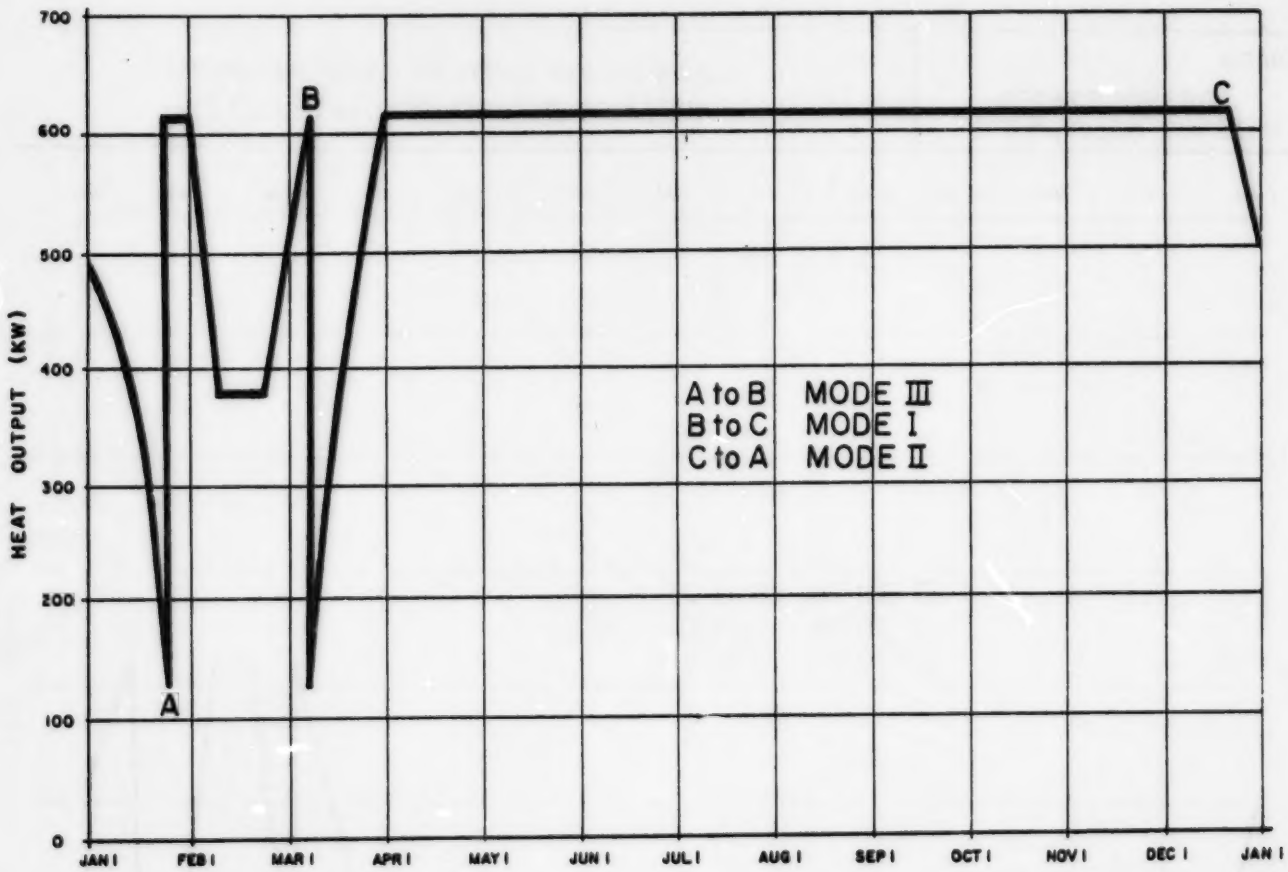
BELOW 3.7 °C



HEAT OUTPUT OF ONE HEAT PUMP
(SEAWATER INLET TO TANKS 2°C. TO 3·7°C.)

CLEARWATER LOBSTER
CLARK'S HARBOUR

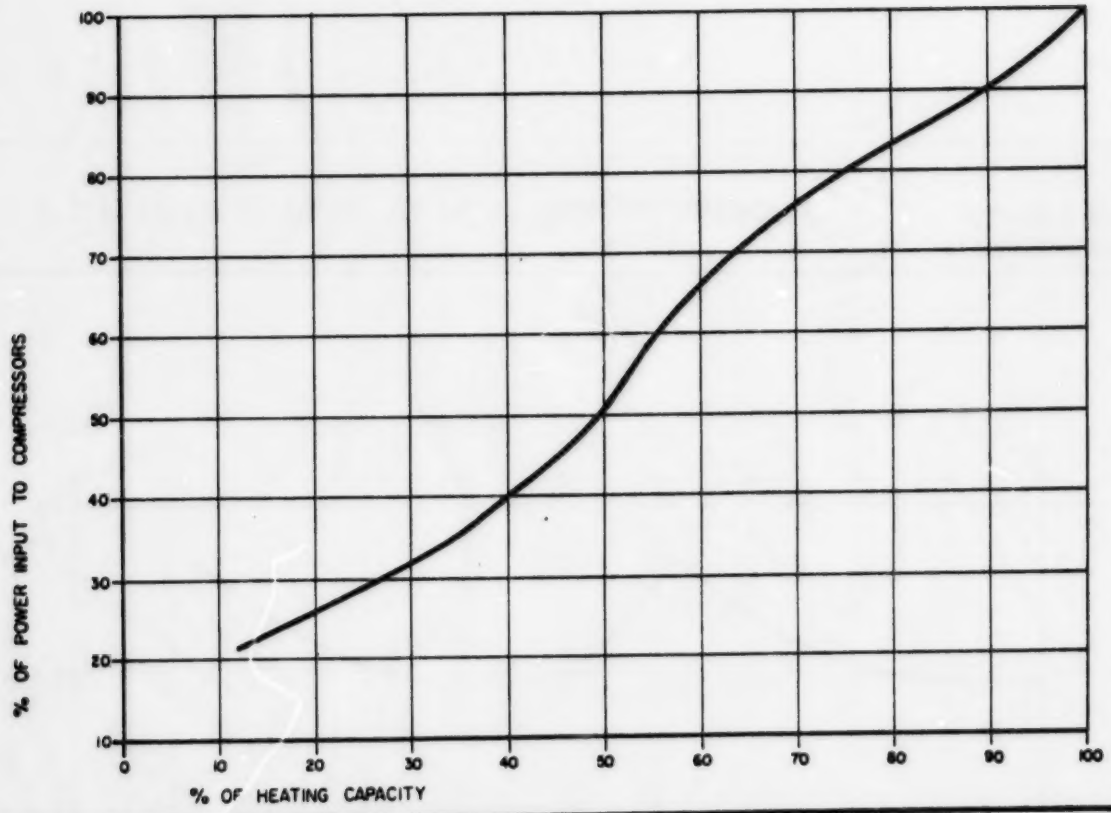
FIGURE 4·2·7



HEAT OUTPUT OF ONE HEAT PUMP
(SEAWATER INLET TO TANKS 2° C TO 2·5°C)

CLEARWATER LOBSTER
CLARKS HARBOUR

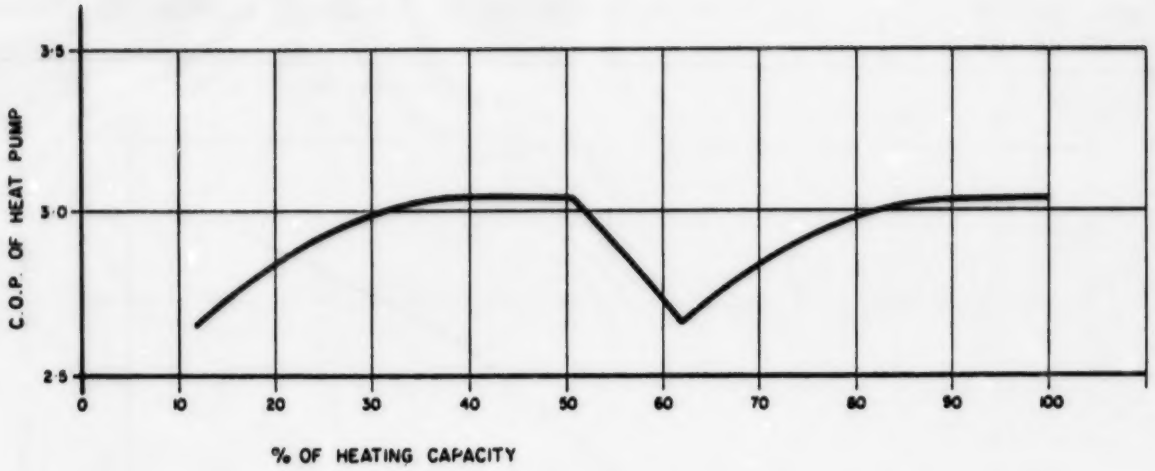
FIGURE 4·2·3



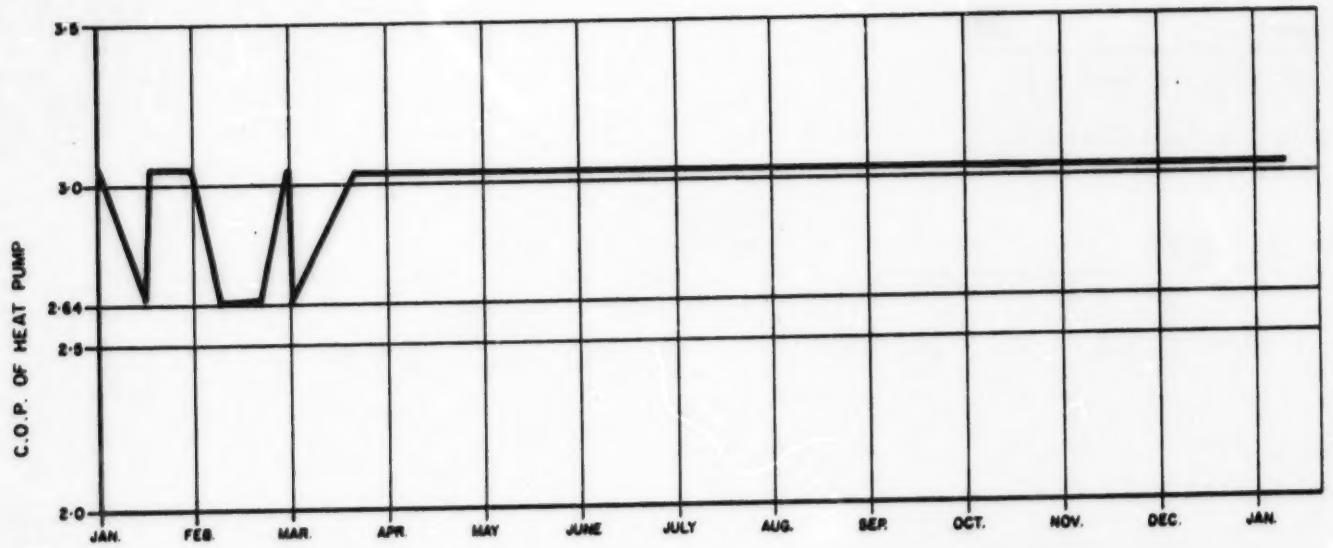
% OF POWER INPUT Vs % OF HEATING CAPACITY

CLEARWATER LOBSTER
CLARK'S HARBOUR

FIGURE 4·2·9



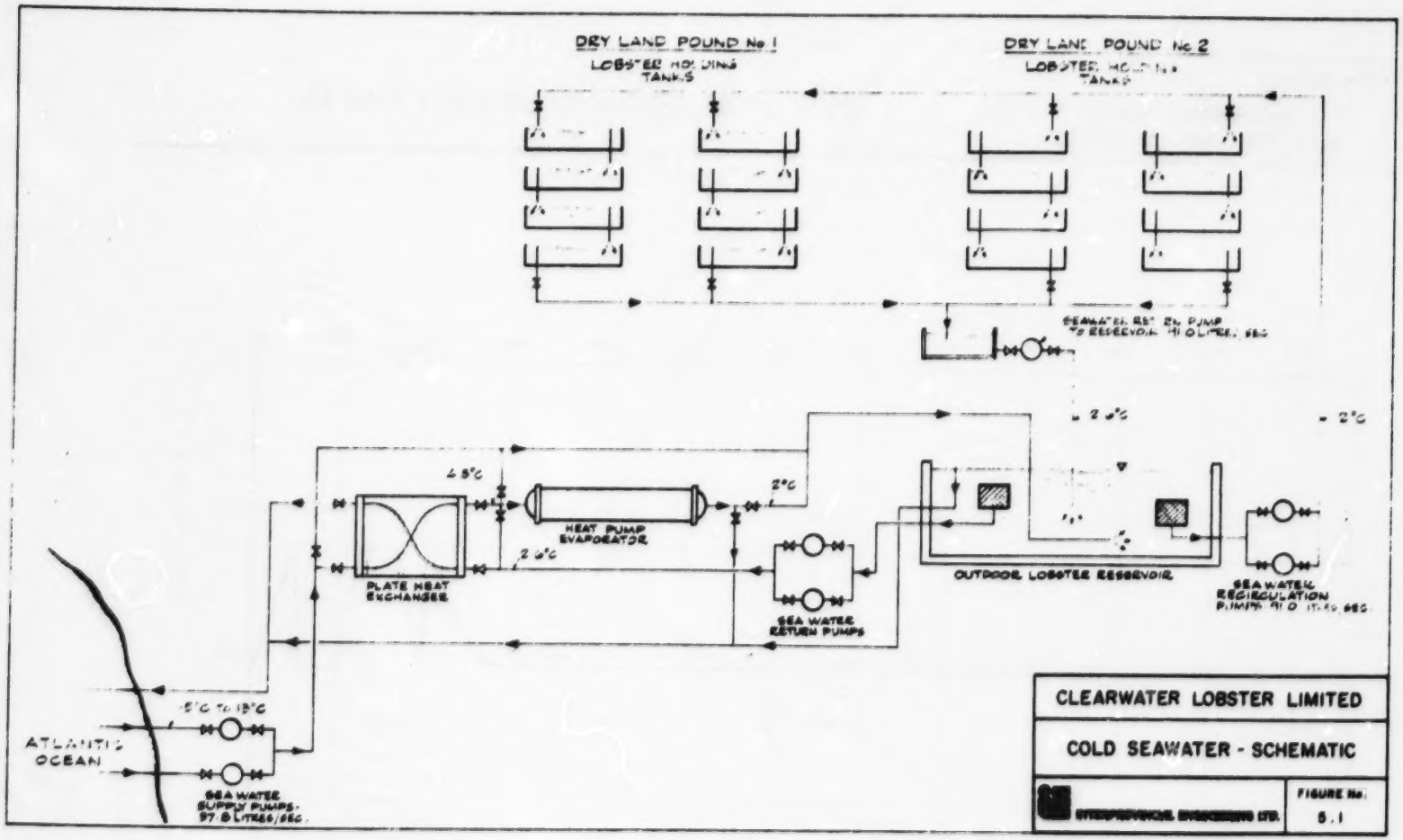
C.O.P. OF HEAT PUMP Vs % OF HEATING CAPACITY	CLEARWATER LOBSTER CLARK'S HARBOUR FIGURE 4·2·10

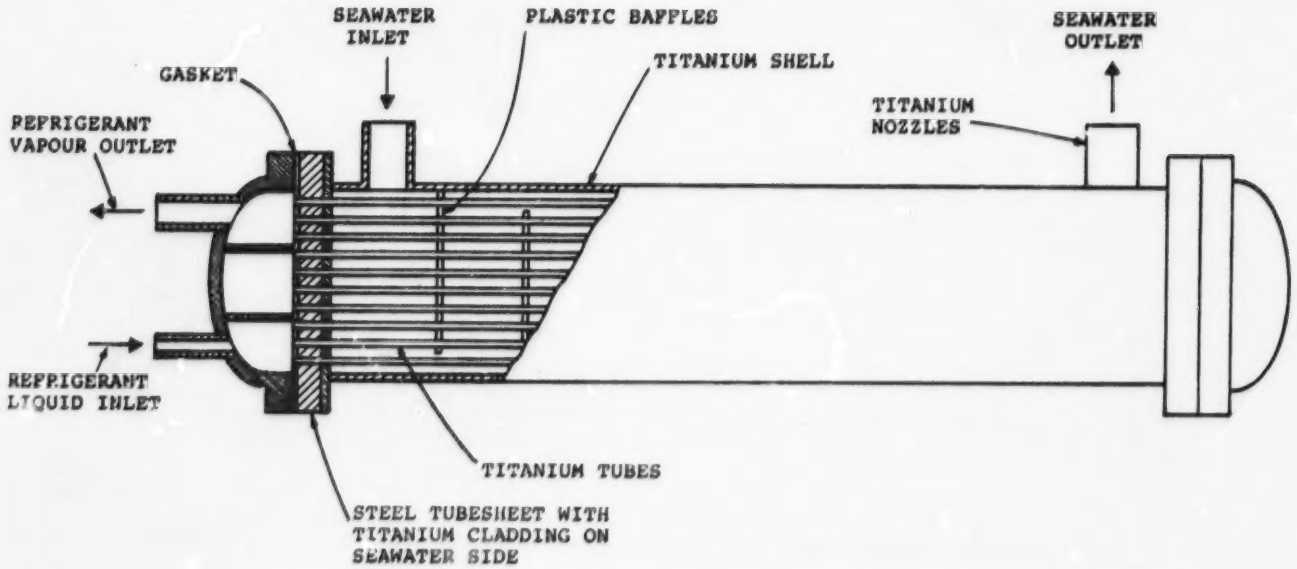


YEARLY C.O.P. OF PROPOSED HEAT PUMP

CLEARWATER LOBSTER
CLARK'S HARBOUR

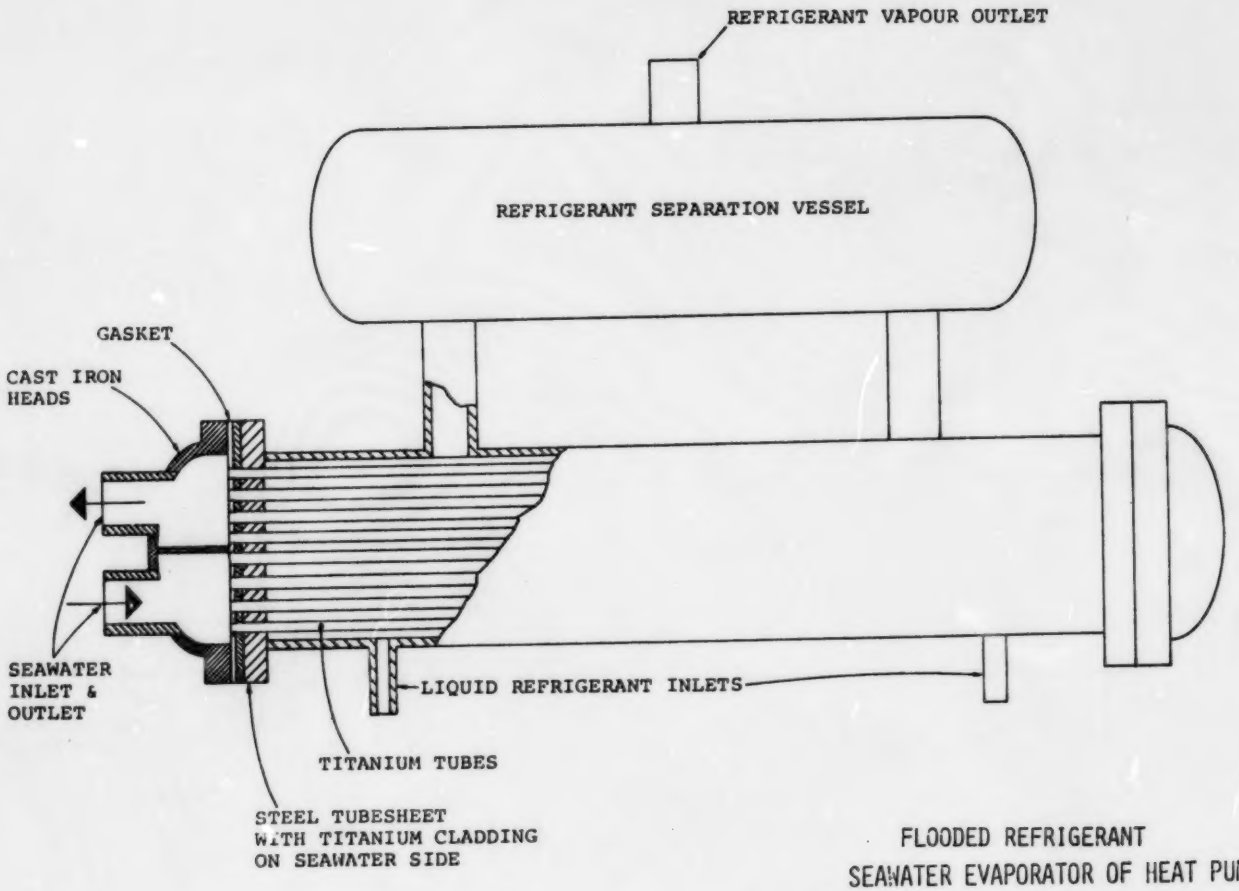
FIGURE 4·2·11


DRY LAND POUND No 1
LOBSTER HOLDING TANKS
DRY LAND POUND No 2
LOBSTER HOLDING TANKS
SEAWATER RECIRCULATION PUMP TO RESERVOIR
4.5°C
2°C
2.6°C
HEAT PUMP EVAPORATOR
PLATE HEAT EXCHANGER
SEA WATER RETURN PUMPS
OUTDOOR LOBSTER RESERVOIR
SEA WATER RECIRCULATION PUMPS
-1°C TO 13°C
ATLANTIC OCEAN
SEA WATER SUPPLY PUMPS - 97.8 LITRES/SEC.
CLEARWATER LOBSTER LIMITED
COLD SEAWATER - SCHEMATIC
FIGURE No.
5.1



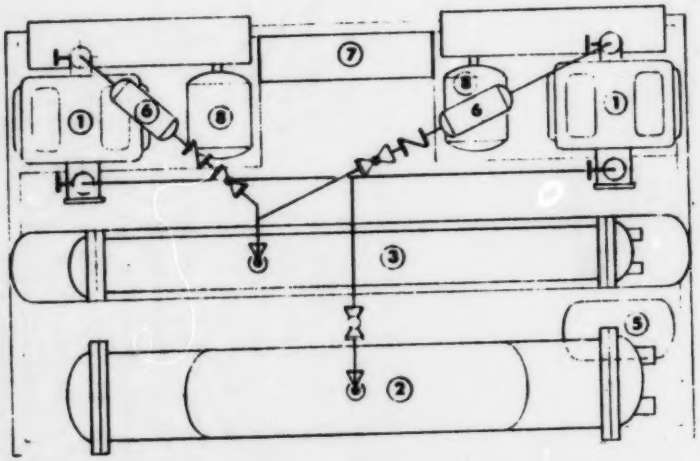
DIRECT EXPANSION
SEAWATER EVAPORATOR OF HEAT PUMP

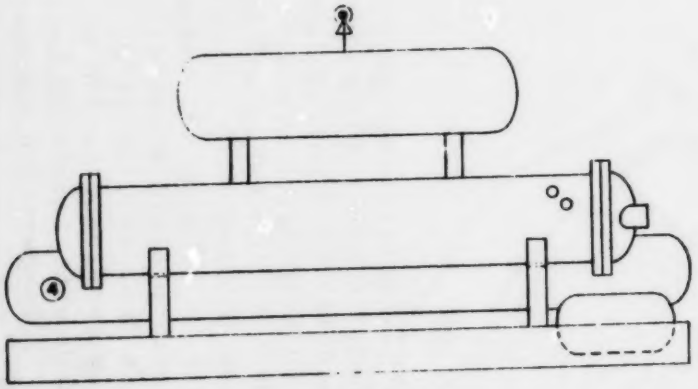
FIGURE 5.2



FLOODED REFRIGERANT
SEAWATER EVAPORATOR OF HEAT PUMP

FIGURE 5.3





LEGEND :

(1) - REFRIGERANT COMPRESSORS.

(2) - SEAWATER EVAPORATOR.

(3) - CONDENSER.

(4) - HIGH PRESSURE RECEIVER.

(5) - OIL RECOVERY VESSEL.

(6) - DISCHARGE LINE OIL SEPARATORS

(7) - ELECTRICAL CONTROL PANELS

(8) - 125 HP. ELECTRIC MOTOR.

CLEARWATER LOBSTER LIMITED	
HEAT PUMP COMPONENTS	
INTERPROVINCIAL ENGINEERING LTD.	FIGURE No. 5.4

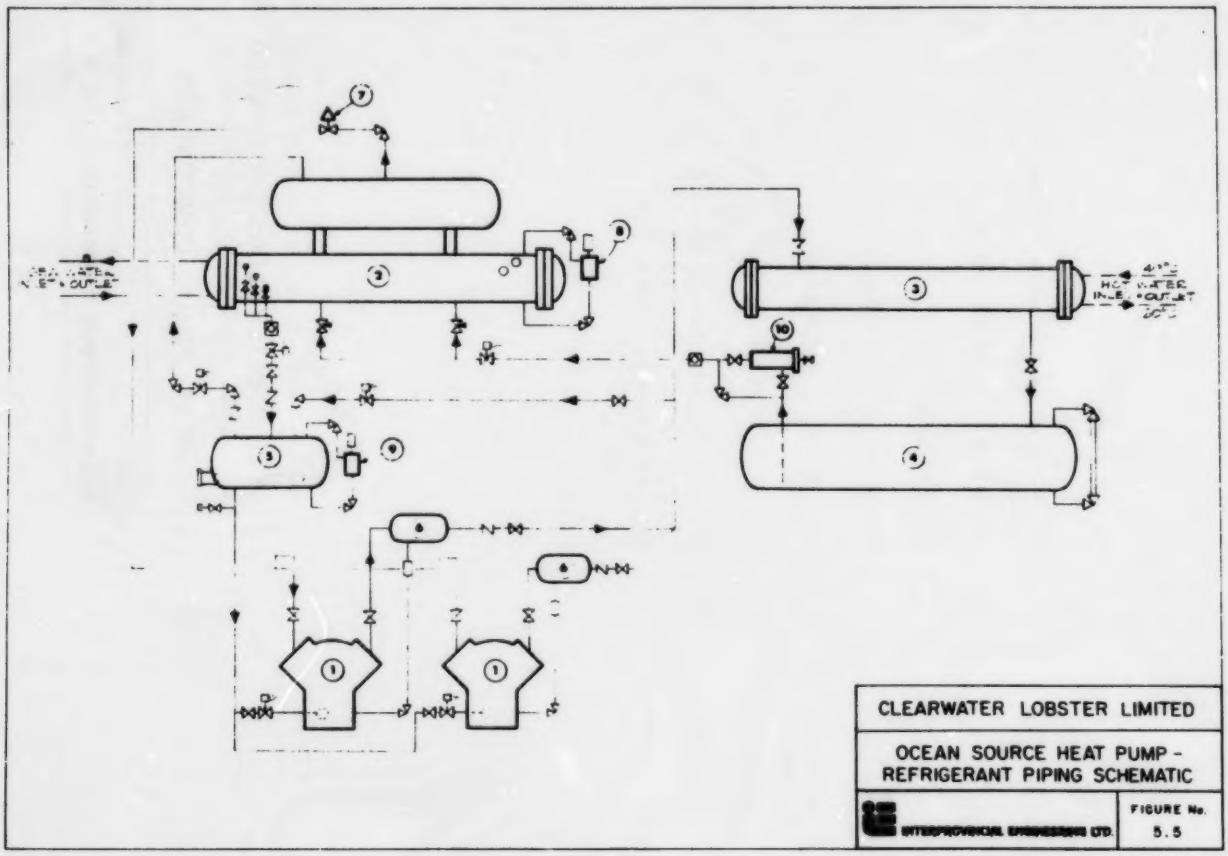
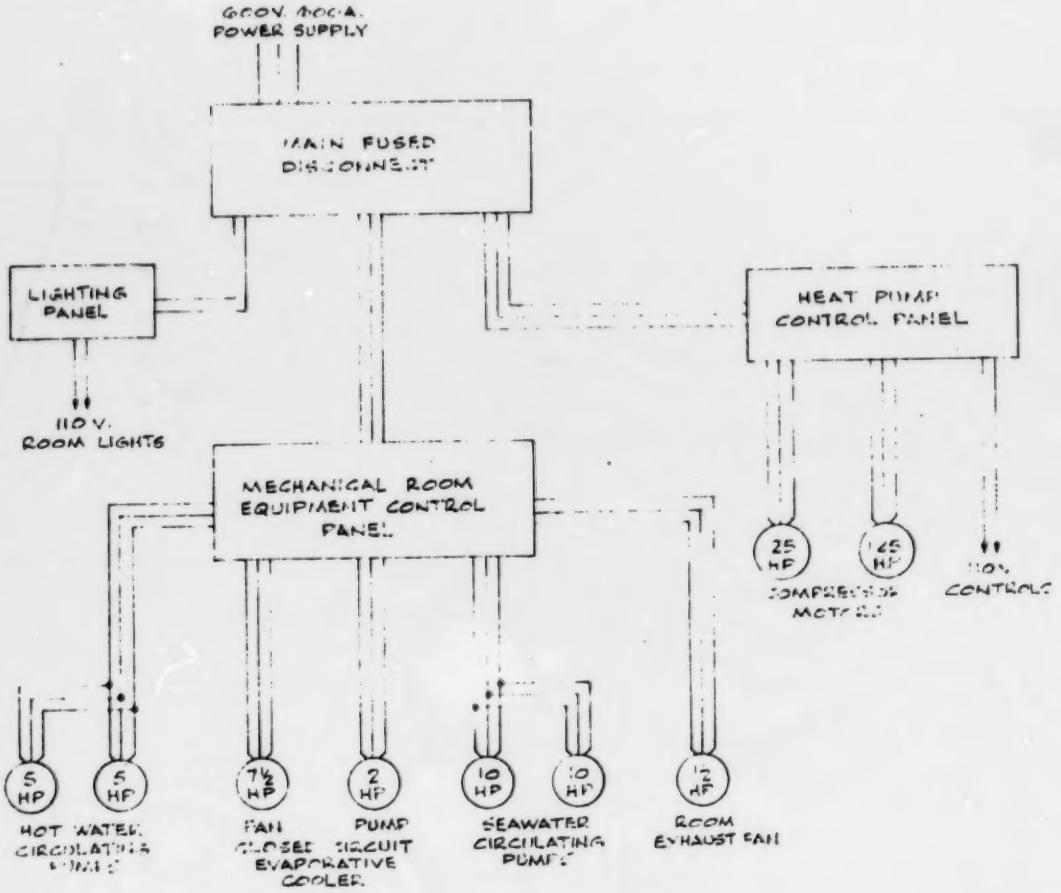
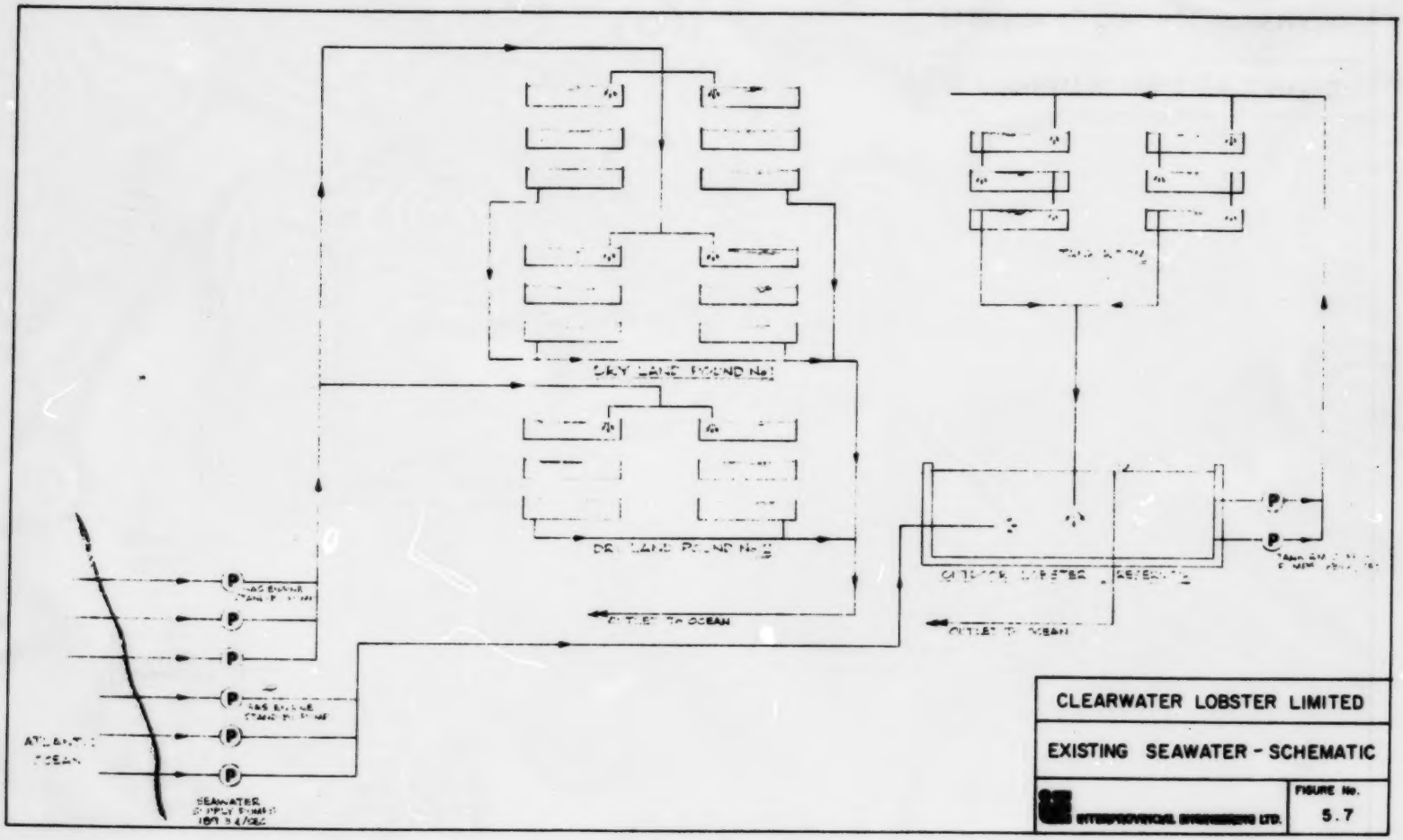


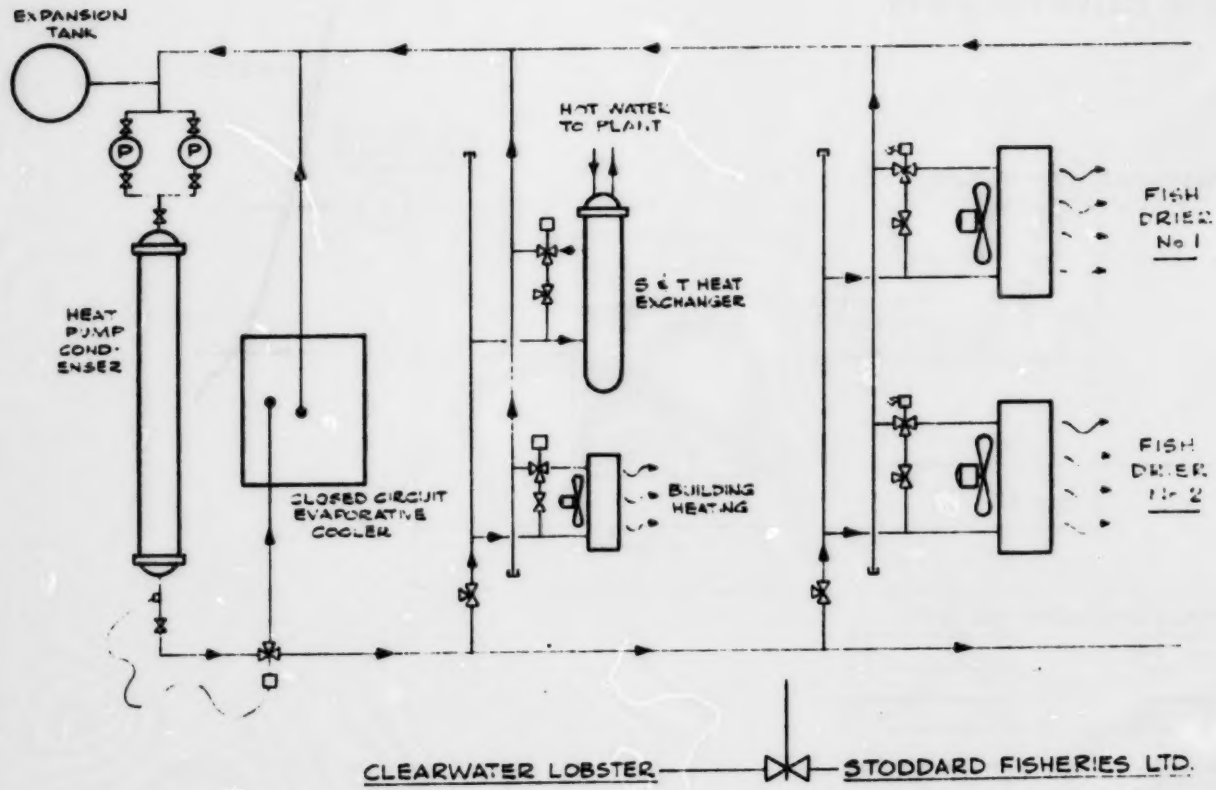
Figure 5.5. 1. Refrigerant compressor each with a capacity of 206.4 kW @ -2.7°C suction and 61.6°C condensing temperature, each complete with 125 hp motor; 2. 600 mm dia. × 3600 mm lg. flooded R-12 seawater evaporator c/w 600 mm dia. × 2400 mm lg. surge drum, 408-75 mm OD titanium tubes and titanium clad tubesheet capacity 412.8 kW when cooling 37.8 litres/s from 4.8°C to 2°C; 3. 400 mm dia. × 3600 mm lg. water cooled R-12 condenser - total heat of rejection 616.8 kW at 61.6°C cond. when heating 13.2 litres/s from 49°C to 60°C; 4. 500 mm dia. × 4800 mm lg. R-12 high pressure receiver; 5. 350 mm dia. × 900 mm lg. oil recovery vessel c/w 600 watt immersion heater; 6. Discharge line oil separators; 7. Temperature compensating suction pressure regulator; 8. Seawater evaporator refrigerant level control float switch; 9. Oil recovery vessel, oil level control float switch; 10. Refrigerant liquid line filter-drier.



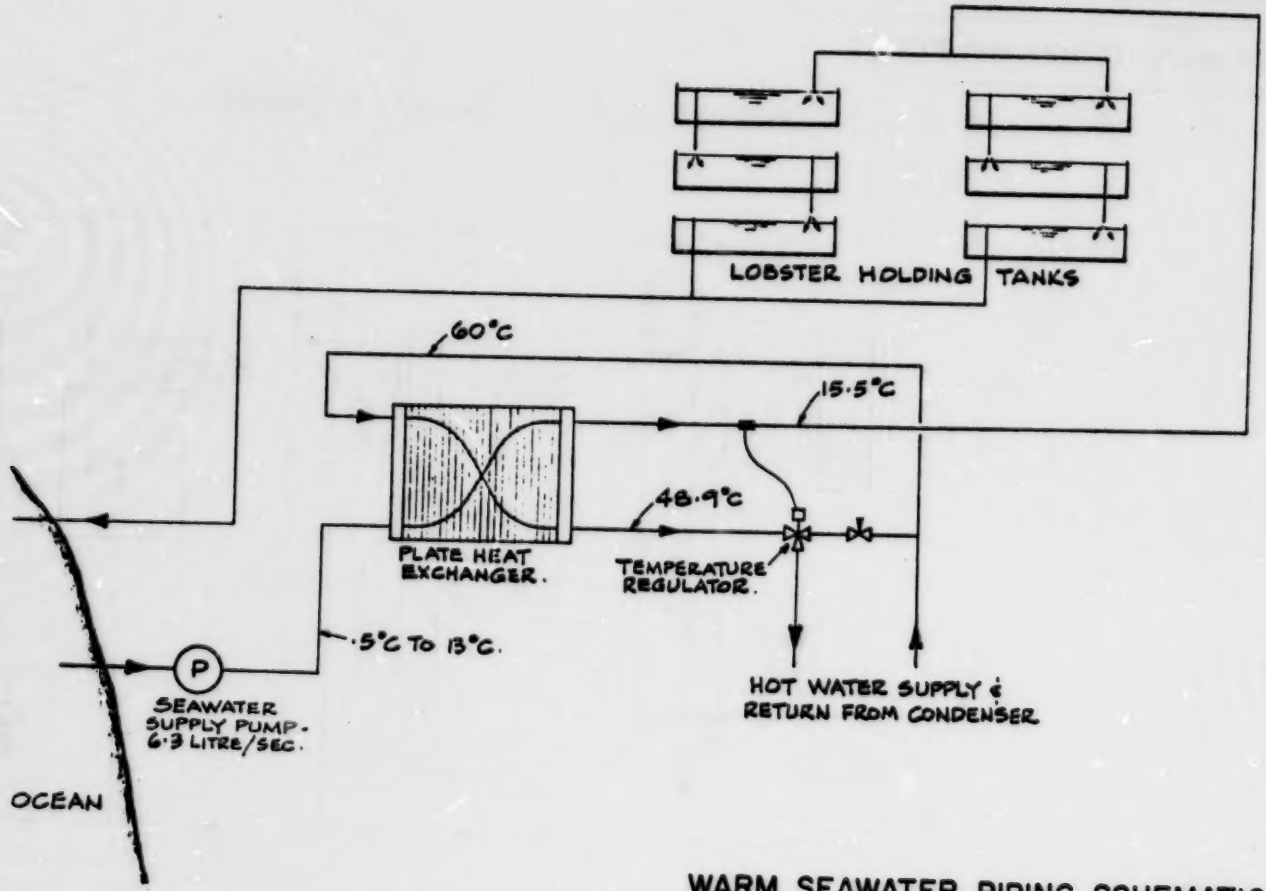
CLEARWATER LOBSTER LIMITED	
ELECTRICAL CONTROL SCHEMATIC	
INTERPROVINCIAL ENGINEERING LTD.	FIGURE No. 5.6



CLEARWATER LOBSTER LIMITED	
EXISTING SEAWATER - SCHEMATIC	
INTERPROVINCIAL ENGINEERING LTD.	FIGURE No. 5.7



CLEARWATER LOBSTER LIMITED	
SCHEMATIC - HEAT DISTRIBUTION	
INTERPROVINCIAL ENGINEERING LTD.	FIGURE No. 6.1



WARM SEAWATER PIPING SCHEMATIC

FIGURE 6·2

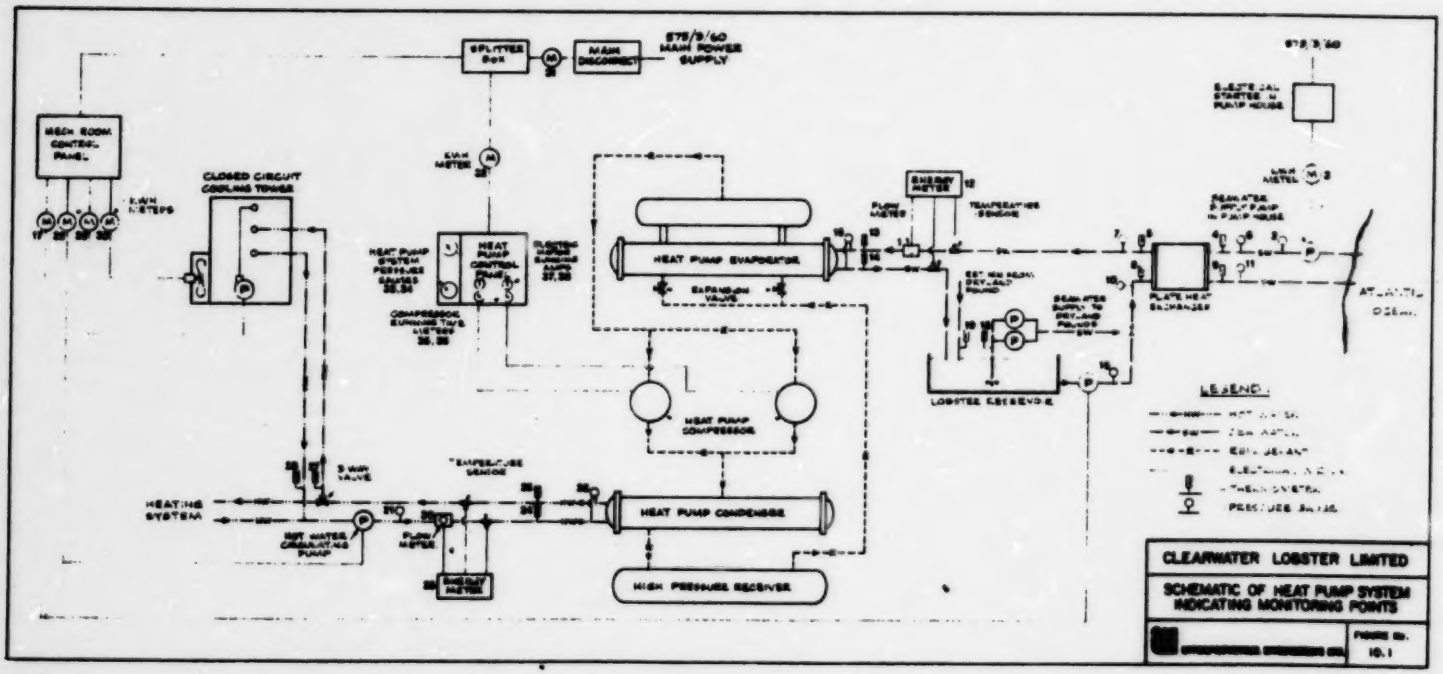


Figure 10.1. -•-•- HW -•-•- , hot water; — — SW — — , sea water; ---R--- , refrigerant; ———— , electrical wiring; , thermometer; , pressure gauge.

TABLES

TABLE 5.1

COMPARISON OF ELECTRIC MOTORS FOR THE HEAT PUMP COMPRESSORS

The following information relates directly to the compressor requirements of the heat pump system at Clearwater. Two 125 HP. motors are required to run the compressors and overcome belt losses.

OPEN DRIP PROOF (ODP) STANDARD MOTOR

At full load this motor has the following specifications:

Efficiency	= 90%
Running Amperage	= 115
Power Factor (PF)	= .90
Service Factor	= 1.15

$$\text{Three Phase Kilowatts} = \frac{(\text{Volts}) \times (\text{Amps}) \times (\text{PF}) \times (1.732)}{1000}$$

$$\text{KW} = \frac{(575\text{V}) \times (115\text{A}) \times (.90) \times (1.732)}{1000} = 103.0 \text{ KW}$$

TOTALLY ENCLOSED FAN COOLED (TEFC) HIGH EFFICIENCY MOTOR

At full load this motor has the following specifications:

Efficiency	= 94.5%
Running Amperes	= 114
Power Factor (PF)	= .89

Service Factor = 1.15

$$KW = \frac{(575V)x(114A)x(.89)x(1.732)}{1000} = 101.0\ KW$$

The approximate operating hours of each of the compressors would be 7896 Hrs per year, at $.04/KWH the yearly operating costs would be:

=(7896 HRS)x(2 compressors)x($0.04/KWH)x(KW used)

=($631.68/KW)x(KW used)

For ODP motors annual operating cost at 103 KW = $65,063.00

For TEFC motors annual operating cost at 101 KW = $63,799.00

The annual savings for high efficiency motors = $ 1,264.00

The two high efficiency motors would cost approximately $5600.00 more than the standard ODP motors therefore the payback for utilizing the high efficiency motors is calculated as follows:

$$Payback = \frac{\$5,600.00}{\$1,264.00} = 4.4\ Years$$

TABLE 6.1

CAPITAL COST FOR HEAT PUMP INSTALLATION

EQUIPMENT

QUANTITY	DESCRIPTION	MANUFACTURER	CANADIAN CONTENT	COST
1	Heat Pump	J. H. Lock & Sons Ltd.	80%	$189,000.00
1	Titanium Plate Heat Exchanger	Alfa-Laval	0%	50,000.00
1	Evaporative Closed Circuit Cooling Tower	Baltimore - Aircoil Ltd.	100%	11,000.00
2	Seawater Return Pumps	Gorman-Rupp Ltd.	100%	9,400.00
2	Hot Water Circulating Pumps	Armstrong Ltd.	100%	2,000.00
-	Refrigerant Field Piping	J. H. Lock & Sons	100%	3,000.00
-	Seawater Piping	-	100%	11,350.00
-	Hot Water Piping	-	100%	7,000.00
-	Electrical Wiring	-	100%	18,000.00
-	Mechanical Room Construction	-	100%	35,000.00
-	Labour to Install Above	-	100%	17,200.00
-	Electrical Control Equipment	-	100%	4,000.00
-	Monitoring Equipment	Various	100%	20,000.00
			SUB-TOTAL	376,950.00
			5% CONTINGENCY	18,850.00
			TOTAL COST	395,800.00

TABLE 6.1A

ALLOCATION OF ENGINEERING COSTS ARE

ESTIMATED AS FOLLOWS

ACTIVITY	DESCRIPTION	ESTIMATED MAN DAYS	ESTIMATED COSTS LABOUR	DISB.	TOTAL
I	DETAILED DESIGN	67	20,400	3,000	23,400
II	EQUIPMENT PROCUREMENT	10	3,600	750	4,350
III	CONSTRUCTION SUPERVISION	20	7,200	2,750	9,950
IV	COMMISSIONING	30	10,800	4,500	15,300
V	AS-BUILT DRAWINGS	12	3,100	1,000	4,100
	TOTAL	139	45,100	12,000	57,100

The amount estimated for disbursements includes:

45 Site Visits Including 600KM/Visit at $.22 and Room and Board = $9,000.

Telephone (long distance), postage, xerox, drawing reproduction & word processing = $3,000.

TOTAL CAPITAL COST FOR INSTALLATION

Equipment	=	$395,800.00
Engineering Labour	=	$ 45,100.00
Engineering Disbursements	=	$ 12.000.00
Cumulative Total	=	$452,900.00

Gov. Project No._____
Requisition No. _____
Date_____Revision No.___

INTERPROVINCIAL ENGINEERING LTD.

CLEARWATER LOBSTER LTD.

CLARK'S HARBOUR, NOVA SCOTIA

	% COMPLETE	WORK BREAKDOWN		MONTH 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Est. Cost Activity/ Milestone	For Govt. Use Only	FINANCIAL ACTIVITIES/MILESTONES: Forecast to Date	Actual to Date	Est. to Comp-letion	Vari-ations
WORK PERFORMANCE		DETAILED DESIGN	P	----	▲															23400					
			A/E																						
		EQUIPMENT PROCUREMENT	P		----	----	----	----	▲											4350					
			A/E																						
		CONSTRUCTION SUPERVISION	P				----	----	----	▲										9950					
			A/E																						
		COMMISSIONING	P						----	----	▲									15300					
			A/E																						
		AS BUILT DRAWINGS	P								----	▲								4100					
			A/E																						
			P																						
			A/E																						
			P																						
			A/E																						
			P																						
			A/E																						
LABOUR	PERSON DAYS	Planned	P	45	22	6	6	9	13	20	18														
		Actual & Expected	A/E																						
EXPENDITURES	BY MONTH	Planned	P	15716	7684	2610	2827	4008	5635	8520	4100														
		Actual & Expected	A/E																						
	CUMULA-TIVE	Planned	P	15716	23400	26010	28837	32845	44480	53000	57100														
		Actual & Expected	A/E																						

TABLE 6.2

ANNUAL OPERATING COSTS

HEAT PUMP ELECTRICAL CONSUMPTION

Total power input (KW) required by compressors at 100% load = 202.0 KW

Total daily operating cost when operating at 100% load

(202.0 KW)x(24 HRS)x($.04/KW) = $193.92/Day

LOAD	DATE	DAYS	COST
100%	01 APR to 20 DEC	264	$51,194.88
80%	21 DEC to 31 DEC 21 MAR to 31 MAR	22	$ 3,412.99
60%	01 JAN to 20 MAR	79	$ 9,191.80
TOTAL		365	$63,799.68

CLOSED CIRCUIT EVAPORATIVE COOLER

The closed circuit evaporative cooler consists of a 7.5 hp two-speed fan, and a 2 hp water circulating pump.

Approximately yearly operating cost = $ 2,000.00

TOTAL HEAT PUMP SYSTEM YEARLY OPERATING COSTS

Heat Pump = $63,800.00

Closed Circuit Evaporative Cooler = $ 2,000.00

Maintenance = $ 6,000.00

TOTAL = $71,800.00

TABLE 10.1

MONITORING POINTS -SEAWATER SYSTEM

SUPPLY PUMP

1. Flowmeter - _____
2. Pressure - _____
3. KWH Meter - _____

PLATE HEAT EXCHANGER

Water Supply

4. Temperature In - _____
5. Temperature Out - _____
6. Pressure In - _____
7. Pressure Out - _____

Water Return

8. Temperature In - _____
9. Temperature Out - _____
10. Pressure In - _____
11. Pressure Out - _____

HEAT PUMP EVAPORATOR

12. Energy Meter - _____
13. Temperature In - _____
14. Temperature Out - _____
15. Differential Pressure - _____

RETURN PUMP

16. Pressure - _____
17. KWH Meter - _____

DISTRIBUTION TO PLANT

18. Supply Temperature - _____
19. Return Temperature - _____

TABLE 10.2

MONITORING POINTS -HOT WATER SYSTEM

CIRCULATING PUMP

20. Water Flowrate - _____
21. Pressure - _____
22. KWH Meter - _____

HEAT PUMP CONDENSER

23. Energy Meter - _____
24. Temperature In - _____
25. Temperature Out - _____
26. Differential Pressure - _____

CLOSED CIRCUIT EVAPORATIVE COOLER

27. Temperature In - _____
28. Temperature Out - _____
29. Pump KWH Meter - _____
30. Fan KWH Meter - _____

TABLE 10.3

MONITORING POINTS -HEAT PUMP SYSTEM

POWER REQUIREMENTS

31. Main Power Supply - _____
32. Heat Pump KWH Meter - _____

REFRIGERATION SYSTEM

33. Suction Pressure - _____
34. Discharge Pressure - _____

COMPRESSORS

35. Running Time Comp.#1 - _____
36. Running Time Comp.#2 - _____
37. Motor Amps. Comp.#1 - _____
38. Motor Amps. Comp.#2 - _____

TABLE 10.4

MONITORING COSTS

Purchase and installation of the monitoring equipment including energy meters, KW-HR meters, pressure gauges, flowmeters and temperature measuring devices is included in the heat pump system work schedule and cost estimate. The estimated cost for conducting the 18 month monitoring program is $63,500.00 as indicated below:

ACTIVITY	DESCRIPTION	ESTIMATED MAN DAYS	ESTIMATED COSTS LABOUR	DIST.	TOTAL
I	IMPLEMENTATION	7	2,500	700	3,200
II	TRAIL MONITORING SYSTEM	8	2,600	2,400	5,000
III	MONITORING AND OPERATIONAL INCIDENTS	62	22,100	8,000	30,000
VI	DATA ANALYSIS AND INTERIM REPORTS	31	11,150	2,000	13,150
V	FINAL REPORT	25	9,000	3,200	12,200
	TOTAL	133	47,350	16,300	63,550

The amount estimated for disursements includes:

40 Site visits including 600KM/visit at $ .22/KM and room and board	= $ 8,600
Typist and word processor charges	= $ 2,600
Three trips to Ottawa	= $ 2,600
Drafting, telephone, xeroxing, drawing reproduction, and computing time	= $ 3,350

Gov. Project No. _____
Requisition No. _____
Date _____ Revision No. ___

INTERPROVINCIAL ENGINEERING LTD.

CLEARWATER LOBSTER LTD.

CLARK'S HARBOUR, NOVA SCOTIA

	% COMPLETE	WORK BREAKDOWN		MONTH 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Est. Cost Activity/ Milestone	For Govt. Use Only	FINANCIAL ACTIVITIES/MILESTONES: Forecast to Date	Actual to Date	Est. to Completion	Variations
WORK PERFORMANCE		IMPLEMENTATION	P	△																				1200					
			A/E																										
		TRIAL MONITORING SYSTEM	P	—	△																			5000					
			A/E																										
		MONITORING AND OPERATIONAL INCIDENTS	P		----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	△	30000					
			A/E																										
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LABOUR	PERSON DAYS	Planned	P	15	6	5	7	5	4	6	4	4	8	4	4	6	5	4	6	4	4	7	25						
		Actual & Expected	A/E																										
EXPENDITURES	BY MONTH	Planned	P	8200	2836	2360	3208	2360	1876	2724	1876	1876	3638	1876	1876	2724	2360	1876	2724	1876	1876	3208	12200						
		Actual & Expected	A/E																										
	CUMULATIVE	Planned	P	8200	11036	13396	16604	18964	20840	23564	25440	27316	30954	32830	34706	37430	39790	41666	44390	46266	48142	51350	63550						
		Actual & Expected	A/E																										

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APPENDIX "A"

STATEMENT OF WORK

APPENDIX A

STATEMENT OF WORK FROM CONTRACT 01SX.31155-2-2680

The information contained below is a direct extract from Annex A of the contract and describes the work the contract is to preform with respect to studing the recovery of heat from salt water in the fish processing industry.

1. Identify the optimum size and performance of the heat pump installation.

2. Select equipment and prepare an engineering design for the proposed application which will assure successful implementation meeting all design and regulatory code requirements.

3. Prepare a statement of economic viability capital cost, operating cost, benefits and payback as perceived by the plant operator.

4. Prepare a statement of energy savings for this plant and estimate its effect on a nation-wide basis.

5. Recognizing that readily available and proven equipment is to be used to permit early implementation, revue the research and developement requirements, which may yield

further benefits. (e.g. heat pump working fluids, heat exchanger technology, material technology, instrumentation and control technology).

6. Discuss the need for any new operating or maintenance skills and its impact upon operational management.

7. Produce interim reports at significant progress points to be agreed.

8. Produce a Final Report incorporating 1 to 6 above.

APPENDIX"B"

COLD WATER STORAGE

APPENDIX B

BENEFITS OF CONSTANTLY COOLED SEAWATER FOR STORAGE OF LOBSTER

There are many benefits derived from providing constant temperature, cold seawater for lobster storage. These include:

Improved Product Quality

The lobsters are markedly less active when kept in seawater at $2^{o}C$. This inactivity prevents much of the cannibalization encountered, as well as preventing loss of quality of the lobster ie: lost claws etc.

One of the present impedient's to longer term storage is the molting cycle of the lobster. Growth is accomplished when the shell (external bone structure) sheds as a new one grows. In the new, soft shelled condition, the lobster is incapable of being shipped and extremely susceptibile to mortality. By maintaining a consistantly cold seawater temperature the molting cycle could be retarded with the commercial benefit that the inventory for storage would be extended. This would allow a qualty product to be available in off season periods.

A second related problem area deals with the inability of

lobster to regain a strong and vigorous state after molting within the storage system. This problem is directly related to diet. While the variables of the present seawater system remain, no conclusive testing can be undertaken in an attempt to remedy the problem. While a great deal remains to be learned of the biology of lobster, the industry does know how susceptible lobster life is to the quality of seawater. Salinity, dissolved oxygen levels, PH factors, and temperature are vital ingredients in water quality. In a system where extremely large quantities of seawater is being pumped and returned without treatment it is impossible to control any of these factors. In a "closed water system", water is recirculated from a central storage reservoir and only small amounts of fresh seawater makeup are required. Under these conditions treatment of all the aforementioned factors is possible. Aiso it should be possible to develop a program for hardening the shell within a reasonable time period. With such a program in effect, lobsters from areas whose quality heretofore meant they could be used only for processing would be introduced into the system and developed into good quality product, capable of being exported. The result would be a higher valued end use, a consequential better return to the fisherman, and greater access by the industry to important new markets.

During the summer and fall months when seawater

temperatures climb above the 10 C mark, a noticeable increase in mortalities of live lobsters results. One of the additional detriments of high seawater temperature is the fact that the lobsters that do survive are in a generally weakened condition. With a large percentage destined for foreign markets their ability to sustain the rigors of shipment is greatly diminished. If the seawater temperature is maintained below 4 C the lobster will be stronger and be able to cope with the rigors of shipment. The benefits from this are two fold; lower mortality rates and a better quality product in the highly competitive world market place.

Increased Loading Ratio

Wilder and Mcleese (1957) reported that when using vigorous lobsters in unfiltered seawater at 4.4 C, there is no serious loss from toxic effect of overcrowding if the water is changed as follows. Every ten days when the ratio of lobsters to water is 240 gram/litre, every two weeks at 180 gram/litre, every three weeks at 120 gram/litre, and every five weeks at 60 gram/litre. Therefore the shorter the period of water replacement is, the higher the loading ratio of lobsters.

Reduced Seawater Flow Requirements

The minimum required flowrates for seawater circulation in lobster holding tanks indicate that as the seawater temperature goes down, the required flowrate is less. The circulation rate required at 4.4°C is half the requirement of 10°C.

Illustrated in the Table below is the Minimum Rate of Circulation (litre/sec) Required for Lobster at a Loading Ratio of 60 gram/litre.

KG of Lobster

°C	25	50	100	300
4.4	.03	.06	.12	.38
10.0	.06	.12	.25	.76
15.5	.09	.19	.38	1.13

(REF: The Storage of Live Lobsters in Recirculted-Refrigerated Tanks., Goggins,P.L., (1979).)

APPENDIX "C"

SEAWATER CORROSION

APPENDIX C

RESISTANCE TO SEAWATER CORROSION OF SELECTED MATERIALS

TITANIUM AND TITANIUM - BASE ALLOYS

Of presently known materials, titanium and its alloys are among the most resistant to the marine environment at ambient temperatures. Almost complete protection from corrosion results from the formation of a thin surface oxide film.

Normally the oxidizing conditions present in typical marine environments promote the passivity of titanium. Mechanically or chemically damaged surfaces are repaired almost instantly.

Not only is titanium completely resistant to seawater environments, but it also is resistant to:

(1) polluted seawater;

(2) diluted seawater found in some harbours;

(3) seawater containing chlorine, ammonia, hydrogen sulfide or excess carbon dioxide, and

(4) hot seawater

Titanium has the ability to withstand extremely high seawater velocities with negligible attack. Numerous investigators have established that titanium will withstand seawter at all velocities of current technical interest. At

ambient temperatures, titanium is completely free from pitting attack in marine environments.

STAINLESS STEELS

The corrosion resistance of stainless steels is attributed to a very thin, stable oxide film on the surface of the alloy which results from the alloying of carbon steels with chromium. Chromium, being a passive metal (corrosion resistant), imparts its passivity to steel when alloyed with it in amounts of 12% or greater. These iron-chromium alloys are very corrosion resistant in oxiding environments because the passive film is re-established whenever a break occurs.

The corrosion resistance of stainless steels is further enhanced by the addition of nickel to the iron-chromium alloys. This group of alloys is popularly known as the 18-8 (18% chromium - 8% nickel) stainless steels.

In general, oxidizing conditions favor passivity (corrosion resistance), while reducing conditions destroy it. Chloride ions are particularly aggressive in destroying this passivity.

Stainless steels usually corrode by pitting and crevice corrosion in seawater. Pits begin by breakdown of the passive film at weak spots or at non-homogeneities. The breakdown is followed by the formation of an electrolytic cell, the anode of which is a minute area of active metal

and the cathode of which is a considerable area of passive metal. The large potential difference characteristic of this "passive-active" cell accounts for considerable flow of current with attendant rapid corrosion (pitting) at the small anode.

Pitting is most likely to occur in the presence of chloride ions (for example, seawater) combined with such depolarizers as oxygen or oxidizing salts. An oxidizing environment is usually necessary for preservation of passivity with accompanying high corrosion resistance, but, unfortunately, it is also a favorable condition for pitting. The oxidizer can often act as a depolarizer for passive-active cells that were established by breakdown of passivity at a specific point or area. The chloride ion in particular can accomplish this breakdown.

Stainless steels can and do pit in aerated seawater (near neutral chloride solution). Pitting is less pronounced in rapidly moving seawater (aerated solution) as compared with partially aerated, stagnant seawater. The flow of seawater carries away corrosion products which would otherwise accumulate at crevices or cracks. It also insures uniform passivity through free access of dissolved oxygen.

As discussed above, stainless steels generally corrode in seawater by pitting and crevice corrosion; therefore, structural integrity can be lost even though 90% to 95% of the exposed surface is uncorroded.

A manifestation of pitting corrosion, whose presence and extent is often overlooked, is tunnel corrosion. Tunnel corrosion is also classified by some as edge, honeycomb, or underfilm corrosion. Tunnel corrosion is insidious because of its nature and because many times it is not apparent from the outside surfaces of the object. It starts as a pit on the surface or on an edge and propagates laterally through the material, many times leaving thin films of uncorroded metal on the exposed surfaces.

Another manifestation of localized attack in stainless steels is oxygen concentration cell corrosion in crevices (usually known as crevice corrosion). This type of corrosion occurs underneath deposits of any kind on the metal surface, underneath barnacles, and at the faying surfaces of a joint. The area of stainless steel that is shielded from the surrounding solution becomes deficient in oxygen, thus creating a difference in oxygen concentration between the shielded and unshielded areas. An electrolytic cell is created, with a difference of potential being generated between the high and low oxygen concentration areas (the low oxygen concentration area becomes the anode of the cell).

ALUMINUM ALLOYS

The resistance of aluminum and its alloys to corrosion is due to a relatively chemically inert film of aluminum oxide

which forms on its surface. As long as this oxide film remains intact the good corrosion resistance is preserved. In oxidizing environments where a sufficient amount of oxidizing agent or oxygen is present to repair any breaks in this protective film, the corrosion resistance of the alumium alloys is maintained.

In general, oxidizing conditions favor the preservation of this passive film, while reducing conditions destroy it. Chloride ions are particularly aggressive in destroying this passive film.

When aluminum is immersed in water, the oxide film thickens much more rapidly than it does in air. The rate of growth decreases with time and reaches a limiting thickness which depends on the temperature, the oxygen content of the water, the ions present, and the PH. In seawater this naturally formed protective film breaks down more readily, and its repair and growth are retarded by the chloride ion.

The corrosion of aluminum alloys in seawater is usually of the pitting and crevice types. Pits begin by breakdown of the protective film at weak spots or at nonhomogeneities. The breakdown is followed by the formation of an electrolytic cell, the anode of which is a minute area of active metal and the cathode of which is a considerable area of passive metal. The large potential difference of this "passive-active" cell accounts for the considerable flow of current with its attendant rapid corrosion at the small anode (pitting).

Pitting is most likely to occur in the presence of chloride ions (for example, in seawater), combined with such cathodic depolarizers as oxygen or oxidizing salts. An oxidizing environment is usually necessary for preservation of a passive protection film with accompanying high corrosion resistance, but, unfortunately, it is also a condition for the occurence of pitting. The oxidizer can often act as a depolarizer for "passive-active" cells established by the breakdown of passivity at a specific point or area. The chloride ion in particular can accomplish this breakdown.

As discussed above, aluminum alloys generally corrode in seawater by pitting and crevice corrosion; therefore, as much as 90 to 95% of the exposed surface can be uncorroded. With such low percentages of the total exposed area affected, corrosion rates calculated from weight loses as mils penetration per year (MPY) can give a misleading picture. The MPY implies a uniform decrease in thickness, which for aluminum alloys is not the case.

Another manfestation of localized attack in aluminum alloys is oxygen concentration cell corrosion in cevices (usually known as crevice corrosion). This type of corrosion occurs underneath deposits of any kind on the metal surface, underneath barnacles, and at the fraying surfaces of joints. The area of the aluminum alloys which is sheltered from the surrounding solution becomes deficient in oxygen, thus creating a difference in oxygen concentration between the shielded and unshielded areas. An electrolytic cell is

created with a difference in electrical potential being generated between the high and low oxygen concentration areas; the low concentration area becomes the anode of the cell. Corrosion occurs at the small anodic area and, because the cathodic area is much larger, the rate of attack is considerably greater than if no such cell were present.

There are two other types of localized corrosion often found in aluminum alloys: intergranular and exfoliation. Intergranular (intercrystalline) attack is selective corrosion of grain boundaries or closely adjacent regions without apprecible attack of the grains or crystals themselves. Exfoliation is a lamellar form of corrosion, resulting from a rapid lateral attack along grain boundaries or striations within the grains parallel to the metal surface. This directional attack results in a leafing action, aggravated by the voluminous corrosion products that causes the uncovered strata to be split apart.

Low weight loses and low corrosion rates accompany these manifestations of localized corrosion. Thus, the integrity of an aluminum alloy structure will be jeopardized if designed solely on the basis of corrosion rates calculated from weight losses rather than on the basis of measured depths of pits and depths of crevice corrosion. Pitting and crevice corrosion can, and do, penetrate aluminum alloys rapidly in seawater, thus rendering them useless in short periods of time.

APPENDIX "D"

GLASS HEAT EXCHANGER

APPENDIX D

CORNING GLASS HEAT EXCHANGER

The Corning shell and tube heat exchanger is theoretically an excellent alternative for transfer of heat between seawater and a refrigerant in the evaporator of a heat pump. Both the heat transfer characteristics and resistance to corrosion are excellent.

The Corning shell and tube heat exchanger designed for high pressure (Model D) is available with carbon steel shell, glass tubes and steel reinforced PTFE tubesheet. However even these high presure models are limited to applications with design pressure requirements below 75 PSI. Individual heat exchangers are available with a maximum heat transfer surface of 280 sq. ft. In larger applications, several units must be connected in parallel to satisfy the heat transfer reuirements.

According to the CSA Refrigeration Code the evaporator for the heat pump system for Clearwater must be designed for a maximum pressure of 150 PSI. Therefore even though from a materials point of view this option is excellent, from a operational standpoint it is not viable.

APPENDIX "E"

COMPRESSORS

APPENDIX E

COMPRESSORS USED IN INDUSTRIAL HEAT PUMPS

RECIPROCATING COMPRESSOR

Reciprocating compressors are the most common type of compressor in every day use. These compressors range in size from fractional horsepower hermetic type to approximately 200 horsepower open type compressors. The reason for their extensive use is the simplicity of the basic design and the reasonable efficiencies which can be achieved.

Compressors of this type are referred to as 'open' or 'hermetic' or sometimes 'semi-hermetic'. An open compressor is one in which the input shaft emerges from the casing which contains the refrigerant via a seal. Drive can then be from an electric motor or any other source of work. With hermetic construction the compressor and electric motor are contained in the same casing which eliminates problems of seal leakage, but can lead to chemical problems if the motor should overheat.

The reciprocating compressor is a piston type compressor which can range from two to sixteen cylinders of varying stroke and bore.

A film of oil is maintained on the cylinder wall, and a

proportion of this will pass out of the compresor and into the working circuit. On the suction side, when this oil returns with the returning refrigerant, it will fall out of suspension and be returned to the crankcase which is kept at suction pressure.

The reciprocating compressor is susceptible to any liquid coming back on the suction side and damage can occur if precautions are not taken.

The reciprocating compressor would be the normal choice for small heat pumps which use up to approximately 150 HP.

SCREW COMPRESSORS

The screw compressor consists of two rotors running together within a sealing sleeve. The rotors are identified as 'male' and 'female'. The male rotor has four lobes on it which are semicircular in section and formed in a helix along the rotor body. The female rotor has a number of flutes and channels in it, formed in the opposite helix to the male.

Compression is achieved in a volume within one channel of the female rotor, sealed by the discharge end face of the casing, the cylindrical inside of the casing, and the interface between the male and female rotors. Discharge occurs through a port in the end of the casing, and all the vapour is discharged, so there is no re-expansion loss.

The screw compressors used in heat pumps are oil injected. The principal of oil injection is that oil is continuously pumped into the suction volume of the compressor, to about 1 per cent by volume. Because the ratio by weight of oil to refrigerant fluid is much greater, the oil removes the heat of compression directly from the refrigerant permitting it to be discharged at low temperatures.

Oil injected screw compressors can effectively meet any combination of pressures which a heat pump would reasonably demand. They are suited to medium and large installations.

CENTRIFUGAL COMPRESSORS

The centrifugal compressor is a well developed machine because of its use in the compression stage of small gas turbines. It also is used in many high-flow applications in the chemical and fuel industries. Unlike the other types described so far, it is exclusively used as a dry compressor, since the presence of oil in the gas or vapour has no benefical effects.

Compressors are available in single stage or two stage form with either open or hermetic drive. Pressure ratios of 3-4 are considered optimum.

Because these compressors are suited to large capacities due to the high volumetric throughputs, and to small temperature differences due to low pressure ratios, they are primarily

used in water/water heat recovery systems, with large shell and tube heat exchangers.